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Potential Environmental Effects of an Offshore Submerged Nuclear Power Plant

Volume II

VIRONMENTAL PROTECTION AGENCY • WATER QUALITY OFFICE

WATER POLLUTION CONTROL RESEARCH SERIES

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27 **Abstract**

Potential environmental effects of wastes from an 1190-Mwe pressurized-water nuclear power plant, submerged 250-ft deep at four representative sites off the U.S. mainland, were studied. The thermal field of the ~~plant's~~ cooling ~~water discharge, and the~~ distribution of radionuclides in the ~~sea, were~~ analyzed. In e[illegible] case, the thermal "[illegible]"

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VOLUME 2

by

GENERAL DYNAMICS
Electric Boat Division

Groton, Connecticut, 06340

for the

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Section 1

GENERAL COMMENTARY ON SITE DESCRIPTIONS

PHYSICAL FEATURES

The physical descriptions of the four representative sites are based on both available data and, where data is lacking, the application of general oceanographic principles. The lack of detailed studies of most locations on the U.S. continental shelves is noteworthy. Most of the data on the physical properties of the water column were obtained from U.S. National Oceanographic Data Center (NODC) summaries. These summaries apply to a 1° square with a limiting depth of 900 feet, thus taking into account a relatively large shelf area. However, these summaries compare favorably with information for the site areas from other data sources. Where warranted, the NODC summaries were modified.

Descriptions of local circulation patterns are particularly scarce. Hence, much dependence must be placed on a single set of observations or one investigation of a given area. Since the format and content of various investigations differ, rigorous format in the descriptions below was not attempted. Indeed, the data-gathering phase of the study made it evident that a completely detailed site description could not be realized within the scope of the study. Consequently, attention was directed toward describing site conditions to a reasonable approximation. With regard to currents, appendix A sets forth the basic precepts on which the expected currents are predicted, where insufficient field data existed for the purpose of modeling.

SEISMIC ACTIVITY

The magnitude of earthquakes can be measured by ground-motion amplitude. On the commonly used Richter scale, the magnitude is the log of the largest amplitude, measured in microns, at 100 kilometers from an earthquake epicenter. Relative earthquake magnitude and frequency of occurrence for the earth are given in the table on the next page (from Howell, 1959).

The total energy in ergs (E_T) released by an earthquake can be estimated from the relationship:

$$\log E_T = 5.8 + 2.4 M_B$$

where M_B is the magnitude of the body wave of greatest amplitude.

	Magnitude	Average Number Per Year
Great earthquakes	8 or more	1.1
Major earthquakes	7-7.9	18
Destructive shocks	6-6.9	120
Damaging shocks (Bikini atom bomb tests)	5-5.9	800
Minor shocks	4-4.9	6,200
Generally felt	3-3.9	49,000
Potentially perceptible (ordinary quarry) blast)	2-2.9	300,000 +

The prediction of earthquakes has not been realized, but some general observations may provide insight. One is that for certain areas the rate of energy release is constant; this means that the longer the period without any shock, the stronger the shock that ultimately may be expected. However, present knowledge is inadequate to apply this observation to quantitative prediction. Another rule-of-thumb is that the more frequently earthquakes have occurred in the past, the more frequently they may be expected to occur in the future. One means of estimating the probability of earthquake occurrence might be by comparison of insurance premium rates for different areas. For the California coastal area and Imperial Valley, the insurance premium in units per $100 in 1932 was $10, highest in the U.S.; the rate for the Atlantic coast was $1, lowest in the U.S. (Howell, 1959). It should be noted, however, that the absence of earthquakes is no assurance that there will be none in the future. For example, Charleston, South Carolina had no record of earthquake activity before or after 1886, but in that year a major temblor caused $50 million damage.

On the U.S. east coast, seismic activity is generally mild, although damaging earthquakes do occur. Of the east coast sites, the Gulf of Maine is an active area, and buildings have been damaged or destroyed by earthquakes (U.S. Navy, 1965). The Nearby Boston area has experienced earthquakes up to Richter 4. The New York Bight area has a much lower probability of earthquake damage: earthquakes have been felt, but no building damage has been recorded (U.S. Navy, 1965). There has been little to no earthquake activity in the Miami area, which is aseismic (U.S. Navy, 1965). However, because the Miami site is on the continental slope, disturbance caused by submarine slides or slumping is a possibility.

Southern California is a major seismic area. In the areas shown by figure 1, 404 earthquakes of magnitude Richter 3 or greater occurred between 1934 and 1958 (Emery, 1960). Of these, five were Richter 5, and two were

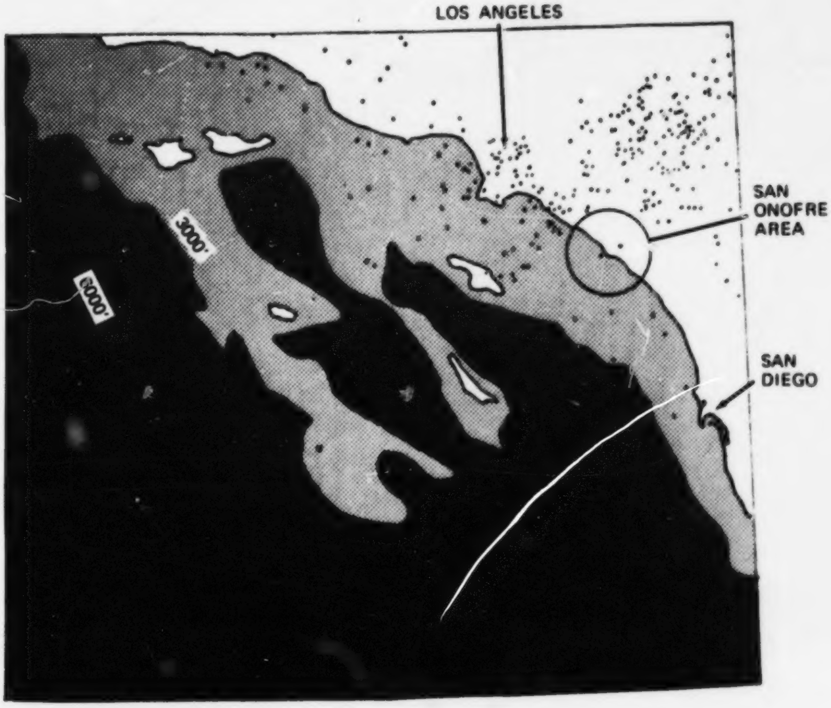

Figure 1. Epicenters of Earthquakes Measured at Richter 3 or Greater, 1934 to 1958 (Positions Accurate to Within 5 km) (Based on Emery, 1960)

Richter 6. Two earthquakes have been recorded near Dana Point, one a few miles inland and one at about the 300-ft isobath, near the shelf edge. Neither of these was major. Earthquake epicenters often correlate with geologic faults. As seen in figure 2, a secondary fault crosses the continental shelf in the Dana Point area (Emery, 1960). These faults, however, are inferred from topographic relations and could be in error.

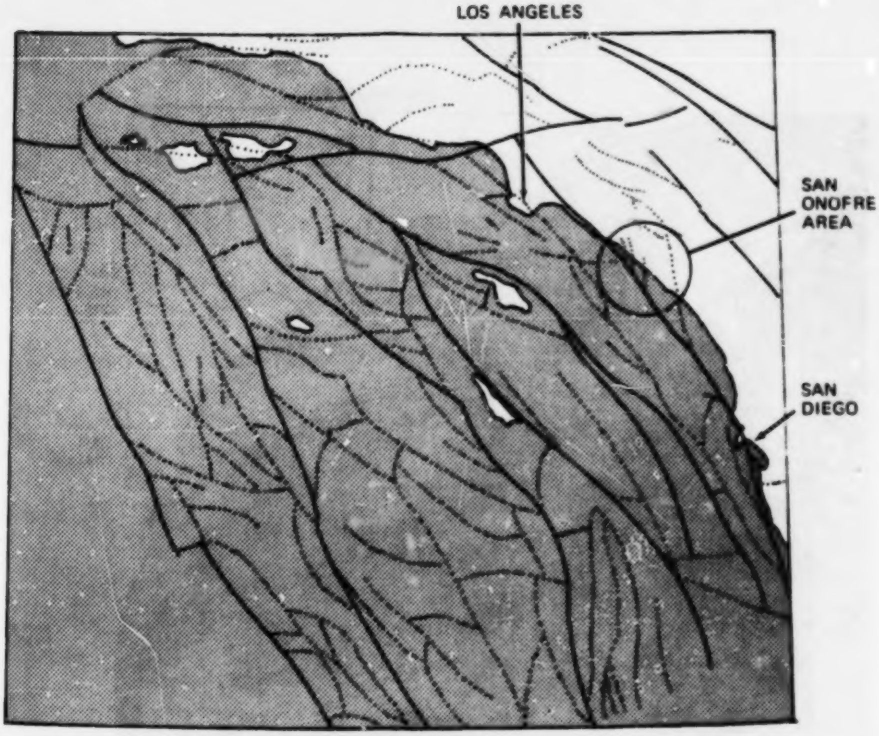

Figure 2. Fault Lines Estimated Chiefly from Sea Floor Topography (Solid Lines Indicate Long Primary Faults; Broken Lines, Secondary Faults)(Based on Emery, 1960)

Figure 3 summarizes the occurrence of damaging earthquakes recorded through 1968. It is apparent that the U.S. coastal areas where seismic activity is pronounced are Alaska, California, Hawaii, Washington, and Massachusetts Bay, with South Carolina being a questionable area. The table below gives quantitative probability of earthquake occurrence for the coastal areas (except Alaska and Hawaii). On the basis of the distribution of earthquake intensities within recorded U.S. seismic history, strain release from earthquakes since 1900, and the relation of strain release to relevant tectonic

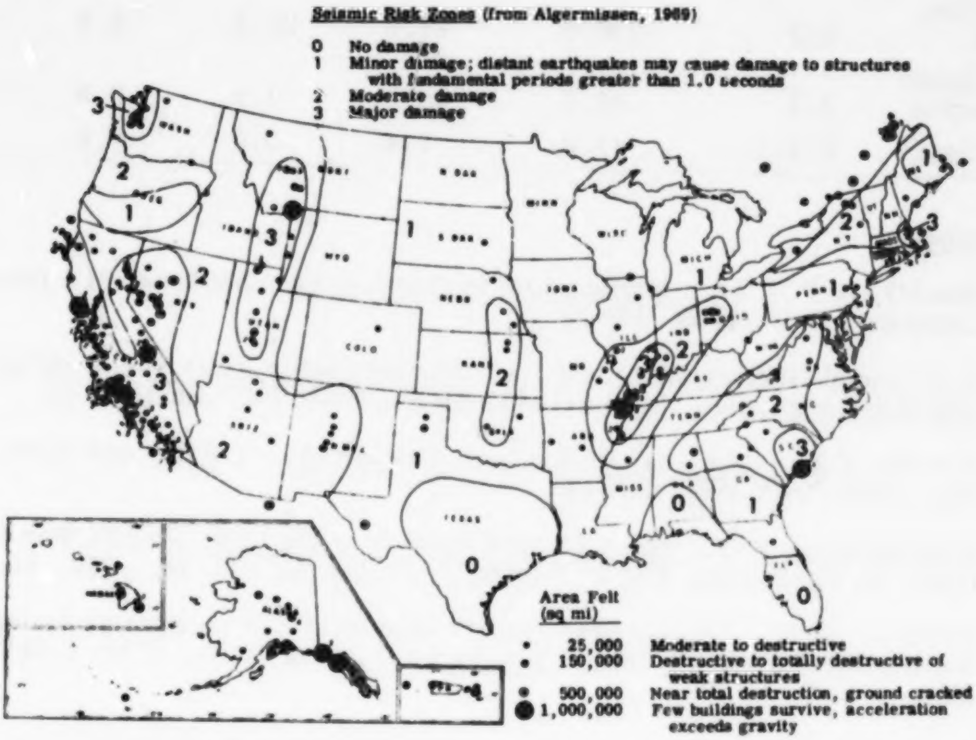
Seismic Risk Zones (from Algermissen, 1969)
0 No damage
1 Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 seconds
2 Moderate damage
3 Major damage
Area Felt (sq mi)
25,000 Moderate to destructive
150,000 Destructive to totally destructive of weak structures
500,000 Near total destruction, ground cracked
1,000,000 Few buildings survive, acceleration exceeds gravity
TEXAS
COLO

Figure 3. Damaging Earthquakes Through 1968 (Origin Unknown, Obtained from Aetna Life Insurance Co., 1971) and Seismic Risk Zones (from Algermissen, 1969)

areas, but without particular regard to earthquake frequency, Algermissen (1969) has divided the contiguous United States into four zones of seismic risk, also shown by figure 3. It is coincidental but interesting, that of his four risk zones, there is one site area in each zone, with California having the highest risk and Florida being essentially aseismic.

Summary of Earthquake Recurrence
(from Algermissen, 1969)

		Earthquakes per 100 Years per 100,000 km^2			
	Risk Zone	Generally Felt	Minor Damage	Moderate Damage	Destructive
California, Nevada	3,2	300.0	84.6	23.8	6.7
Puget Sound Washington	3,2	68.0	16.3	3.9	0.9
East Coast	3,2,1	12.8	3.4	0.9	0.2

References

1. Howell, B.F., Jr., Introduction to Geophysics. McGraw-Hill Book Company, Inc., 1959, 399 pp.
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3. Emery, K.O., The Sea Off Southern California, J. Wiley and Sons, Inc., New York 1960, 366 pp.
4. Algermissen, S.T., Seismic Risk Studies in the U.S. Fourth World Conf. on Earthquake Eng'g, Santiago, Chile, Jan. 13-18, 1969, 10 pp.
5. Wallace, R.E., "Earthquake Recurrence Intervals on the San Andreas Fault," Geological Society of American Bulletin, v 81, 1970, p 2875-2890, 8 figs.

BIOLOGICAL GENERALIZATIONS

In the biological descriptions the objectives were to:

1. Identify the species likely to be present.
2. Identify the most abundant or dominant species.
3. Indicate the distribution and quantities of dominant species in space and time.
4. Describe the interrelationships among species and environment.
5. Predict the fouling potentiality at water depths of about 75 meters.

If the distribution of organisms and a potential pollutant are known quantitatively in space and time, and the response or tolerance of the organisms to the concentration of the pollutant with exposure over time are known, the potential biological effect on specific organisms can be predicted. Evaluation of the ecological effects requires further knowledge of the quantitative interrelationships among the organisms present.

Review of a substantial sampling of the biological information available leads to some generalizations that can be summarized as follows:

1. The biology of offshore areas has been only studied in very broad outline, because of the difficulties of doing scientific work at sea and, more especially, the limitations imposed by the expensive equipment and manpower required for oceanographic research. Of the four areas examined, offshore waters of southern California have been studied the most thoroughly followed by those of Maine, southeastern Florida, and the New York Bight.
2. The biology of offshore waters is still essentially in a descriptive stage. Although larger species occurring offshore have been listed, all species have not been identified. This is especially true of microscopic forms, which are difficult to sample, handle, and identify; and obscure forms which have undergone little taxonomic treatment.
3. The quantitative information on spatial or temporal distribution of organisms is difficult to compare or summarize, because of differences in sampling techniques and devices used by various investigators. Since sampling stations are often 40 nm or more apart, numbers must be applied with caution.
4. The relative importance of the various species to the economy of the sea is only known in the broadest outline. For the purpose of this study, the simplifying assumption was made that the dominant species (largest standing crop) of various groups are the most important to the economy of the area. Actually, less abundant species that multiply rapidly and are consumed rapidly might be ecologically more important, since they would induce more rapid turnover of energy even though their standing crop were low.
5. The foods and feeding habits of important species are only known for a few species, mostly those of commercial importance. In

the case of fish, for example, although various larval or juvenile stages of fish are selective in the foods they consume, many adult fish appear to be omnivorous in their feeding habits. Insufficient attention has been paid, it seems, to the role of benthic organisms in the food chain generally, and in supporting commercial and sport fisheries.

6. Although many species of marine organisms have been allocated to biogeographical provinces, little is known of total populations or the populations characteristic to a particular area. Knowledge of total populations is important for assessing the ecological effects of the offshore power plant.

7. ✓ The four areas have more similarities than dissimilarities in their biological characteristics. Although the species playing basic roles differ, the groups involved are similar. On the basis of abundance, diatoms (Chaetoceros) are the most abundant phytoplankton at all sites except Florida. The phytoplankton play the role of the first trophic level in the food webs of aquatic environments -- a role analogous to that of grasses and grains on land. At all four locations, the zooplankton and the benthos are dominated by copepods and polychaete worms, respectively. The zooplankton largely make up the second trophic level in the food web, their role being analogous to that of the grazing animals on land. The benthic organisms play various roles, depending on the species, but the zooplankton together with the benthic organisms support the third trophic level, which includes plankton, feeding forms, and foraging fish. The southern California region is biologically unique in commonly having kelp beds, mammals such as seals and whales, and dinoflagellate blooms, although these are not necessarily characteristic of the hypothetical plant site. The waters off southern Florida are the only ones adjacent to the continental United States where decidedly tropical conditions and coral reefs occur. The Maine region is notable for its productive commercial fisheries.

8. The phytoplankton are most abundant in the spring, in neritic (shelf) waters and at depths of 10 to 50 meters, and least abun-

dant in the winter, in oceanic waters, and deeper than 50 meters. However, the euphotic zone (zone of net photosynthesis) is about 100 meters deep in the Florida Current.

9. The zooplankton are most abundant in the late spring and early summer, and in neritic waters. Various groups occupy all zones of the water column, and some groups such as salps may occur in very large numbers locally at times. Most groups exhibit diurnal vertical migration, and some species migrate as much as 80 meters. Many species of larval fish tend to occupy water near the surface, but larvae of almost all groups occupy a broad depth range. In terms of economic interest to man, carnivorous, zooplanktonic predators such as chaetognaths, siphonophores, and thaliacea (tunicates) are less desirable than herbivorous copepods and euphausids which serve as desirable fish food. Destruction of the former by entrainment through the power plant's condenser, if this occurs, might prove to be desirable.

10. The fish of commercial or sport value are generally found over the inner shelf or in favorable locations such as banks or ridges far offshore. Fish are broadly classified into pelagic types, which occupy all depths of the water column, and demersal types which tend to feed and remain near the bottom. Most fish of commercial or sport value are highly mobile and exhibit schooling and migration traits, except during egg and larval stages. Inshore-offshore migration is very common. Eggs and larval stages of fish are most abundant in the water column during the late spring and summer. The complex behavior of fish in the presence of structures and thermal or water current gradients is especially notable.

11. Benthic organisms are associated with particular bottom sediments which may be generally characterized as rocky, sandy, or muddy. Some species live attached to objects or crawl about on the seabed; other bury themselves in the sediments to depths of as much as 30 cm (epi- and infauna species). Muddy bottoms usually contain the largest biomass (amount of living matter) per unit area, while sandy bottoms have the least. However, many

of the important shellfish and crustacean fisheries are found in rocky or sand regions. Shrimp are found on muddy bottoms.

12. Fouling of bottom structures decreases with distance from shore and depth. At depths of 75 meters, fouling by various algae will be absent except possibly off southeastern Florida. Fouling should consist primarily of sessile attaching organisms belonging to such groups as hydroids, sea anemones, bryozoa, tunicates, and calcareous polycheate worms. If a fouling community is allowed to develop, mobile forms feeding on the sessile animals can be anticipated.

13. Bacteria and other fungi, which complete the transformation of organic compounds into inorganic compounds used as nutrients by plants, can be ignored because of their ubiquity and generally high reproductive capacity.

Section 2

SITE DESCRIPTION FOR THE GULF OF MAINE REGION

PHYSICAL DESCRIPTION (WISCASSET AREA)

Figure 4 shows soundings of the Wiscasset area, representative of a Gulf of Maine site. The Gulf of Maine is a more or less enclosed coastal sea, its seaward edge contained by a series of shallow sills extending from Nantucket to Cape Sable, with only three narrow passages breeching this sill boundary. The waters of the Gulf of Maine are derived from several sources: (1) high salinity (~35 ^{o}/oo), cold (6-8°C) slope water flows intermittently into the Gulf as a bottom current; (2) in the spring, the Nova Scotian current of cold low-salinity water flows into the Gulf at the surface from around Cape Sable -- this current slackens or increases at other times of the year; (3) a surface drift into the Gulf, offshore from Cape Sable is made up of a mixture of cold banks water, slope water, and tropic water; (4) although there is generally no surface drift across Georges Bank into the Gulf, occasional overflows of tropic water may occur; and (5) rainfall and river discharge contribute fresh water from a watershed of roughly 64,000 sq mi. It is not believed that the Gulf of Maine receives water from the Labrador Current (Bigelow, 1928). Water flows out of the Gulf as a surface current around Nantucket Island and, to a lesser extent, around the eastern end of Georges Bank and the Eastern Channel.

Temperature of Gulf of Maine water is due to the interaction of several factors, the principal ones being its location leeward of the continent and the severe climate of the adjacent land; lesser influences being the influx of currents. However, in spite of its latitude and the land climate, the Gulf waters are not abnormally cold and should not be described as "arctic" (Bigelow, 1928). Solar warming is the chief source of heat for the surface waters.

In the coastal waters near the site area, tidal stirring mixes the water fairly well from surface to bottom. In winter, water temperature is nearly uniform at all depths, surface water being slightly cooler than the deeper water (see table 1 and figure 5). In spring and summer the surface water warms only slightly more rapidly than the deeper water, so that the period of a strong thermocline is only 2 or 3 months, instead of 5 to 6 months as in more sou-

Table 1. Physical Properties of Wiscasset Site

Depth (m)	Density (ρ_t) Ave	Density (ρ_t) Max	Density (ρ_t) Min	Temperature (°C) Ave	Temperature (°C) Max	Temperature (°C) Min	Salinity (°/oo) Ave	Salinity (°/oo) Max	Salinity (°/oo) Min
				Winter					
0	25.68	26.16	25.12	5.92	8.33	2.20	32.61	33.10	31.83
10	25.74	26.16	25.12	6.06	8.68	2.70	32.69	33.10	31.92
20	25.77	26.15	25.08	6.16	8.86	2.80	32.76	33.11	32.34
30	25.79	26.15	25.11	6.22	8.84	2.80	32.79	33.13	32.88
50	25.83	26.17	25.30	6.34	8.48	2.9	32.86	33.15	32.52
75	25.92	26.20	25.64	6.26	8.45	2.90	32.95	33.17	32.72
100	26.04	26.22	25.86	6.11	8.19	3.23	33.08	33.30	32.82
125	26.12	26.22	25.99	5.92	6.56	5.19	33.15	33.32	32.88
				Summer					
0	23.48	24.52	22.49	14.22	18.80	10.00	31.55	32.66	30.48
10	24.09	24.87	22.71	11.91	17.77	7.31	31.76	32.80	30.68
20	24.74	15.41	23.37	9.49	15.00	5.61	32.03	32.94	31.20
30	25.10	25.62	23.86	7.77	12.93	4.82	32.18	33.06	31.36
50	25.41	25.99	24.95	6.44	11.75	3.95	32.36	33.29	31.60
75	25.68	26.29	25.19	5.72	10.27	3.55	32.54	33.52	31.89
100	25.91	26.42	25.43	5.28	8.80	3.42	32.75	33.70	32.20
125	26.11	26.58	25.35	5.24	7.90	4.40	33.00	33.82	32.10

*Temperature is given in degrees Celsius, salinity in parts per thousand (°/oo), and density in sigma-t units (where, e.g., 24.39 represents a specific gravity of 1.02439).

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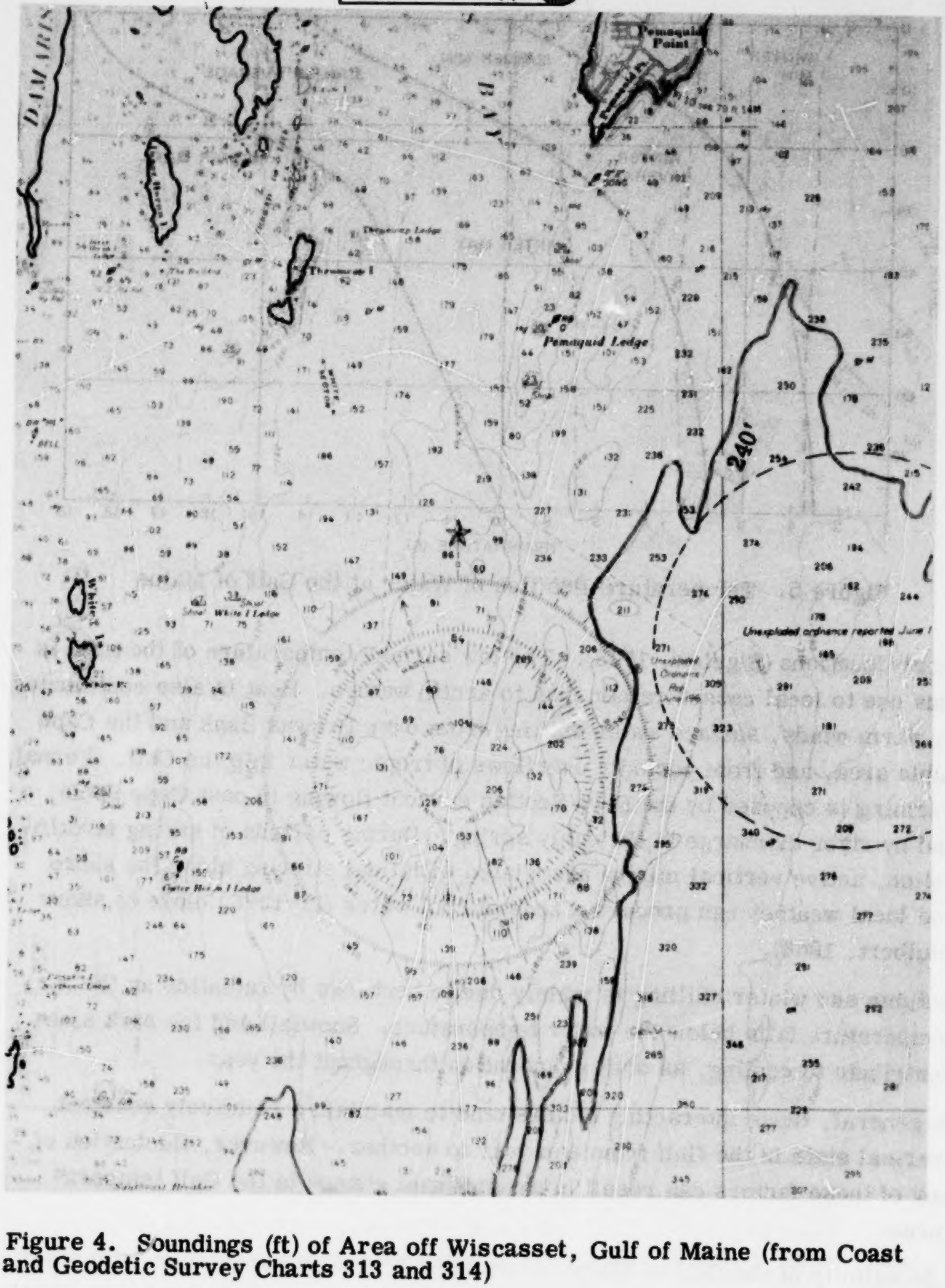
Pemaquid Point
BAY
Thrumcap Ledge
Thrumcap I
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White I
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Outer Heron I Ledge
240'
Unexploded ordnance reported June I
Unexploded Ordnance
Southwest Breaker

Figure 4. Soundings (ft) of Area off Wiscasset, Gulf of Maine (from Coast and Geodetic Survey Charts 313 and 314)

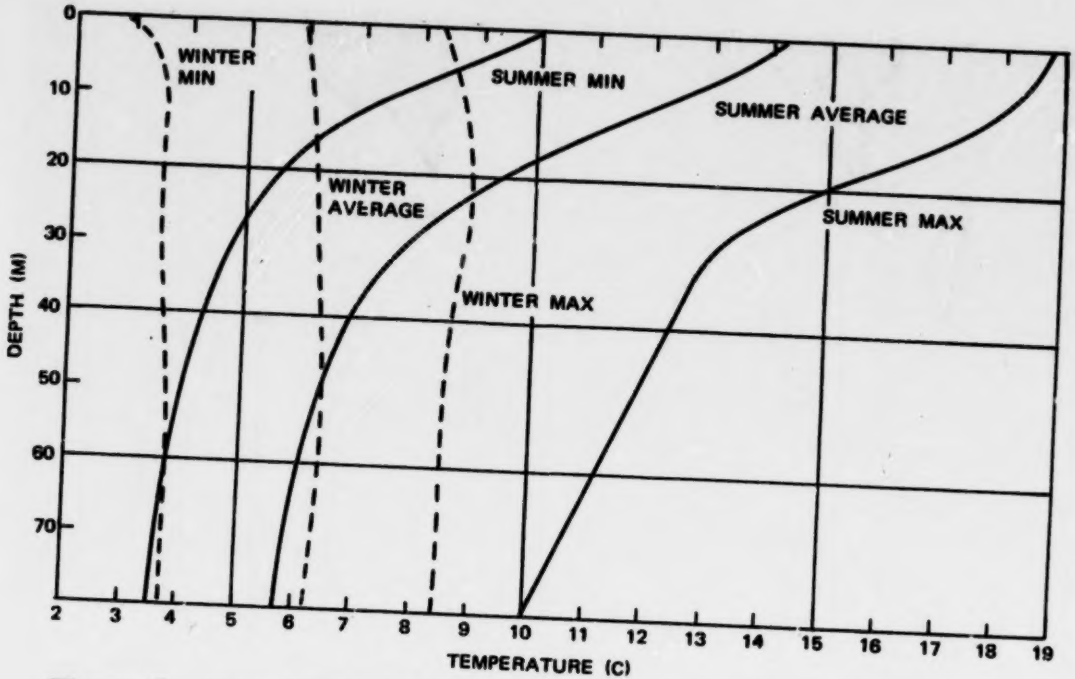


Figure 5. Temperature Profiles of Water at the Gulf of Maine

therly locations (Bigelow, 1928). The low surface temperature of the area is thus due to local causes rather than to arctic waters. Heat is also contributed by warm winds, surface water drifting from over Browns Bank and the Cape Sable area, and from periodic overflows of tropic water into the Gulf. Vernal warming is opposed by the Nova Scotian current flowing in past Cape Sable, and by river discharge in the early spring. During periods of strong stratification, active vertical mixing associated with tidal stirring along the shore and local weather can produce a zone of cool water (11-12^{o}C) close to shore (Hulburt, 1968).

Autumn and winter chilling is mainly due to heat loss by radiation as the air temperature falls below the water temperature. Snowfall and ice melt also contribute to cooling, as does evaporation throughout the year.

In general, these interacting factors tend to maintain a relatively constant thermal state in the Gulf from one year to another. However, fluctuation of any of these factors can result in a significant change in the Gulf temperatures.

The salinity of the Gulf of Maine is low (32-33 ^{o}/oo) in comparison with other enclosed seas and with the Gulf Stream seaward of the Gulf (~35 ^{o}/oo). Tidal stirring minimizes the vertical range of salinity in the coastal waters (generally less than 1 ^{o}/oo). Seasonal variations are typical of coastal areas with coastal waters freshening with spring runoff, and then increasing in salinity again slowly through the summer and fall.

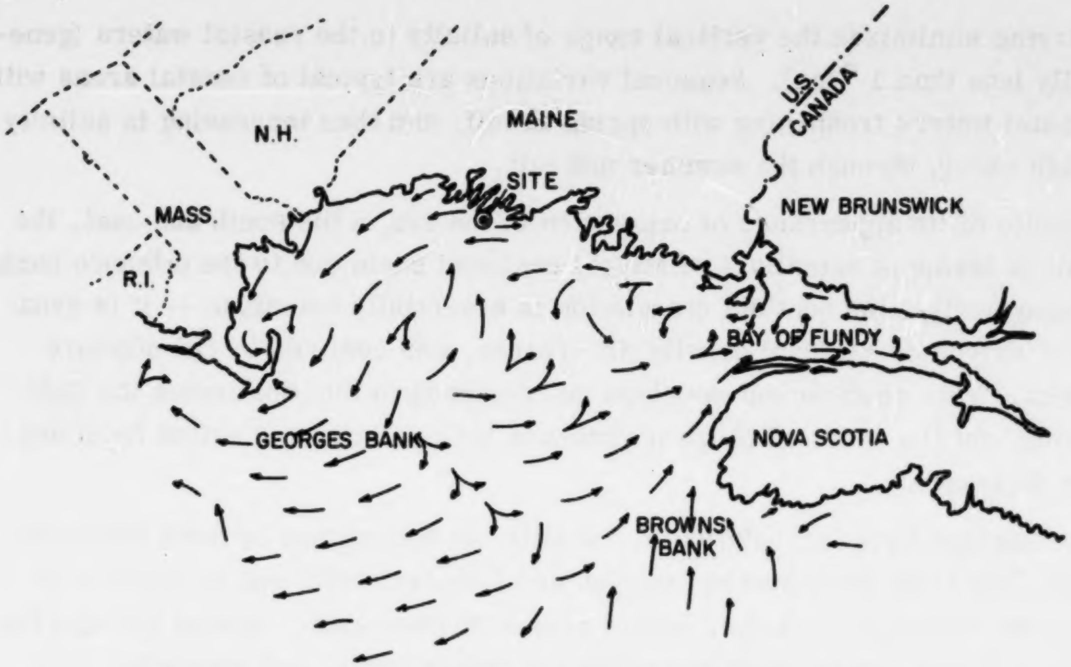
In spite of its appearance of being open to the sea in the south and east, the Gulf of Maine is actually a relatively enclosed basin due to the offshore banks. Consequently, the nontidal circulation is essentially estuarine -- it is dynamic, driven by regional density differences, and confined by the offshore banks. This containment develops an eddy pattern that dominates the Gulf throughout the year, although it varies in both velocity and extent from season to season.

The surface water circulation in the Gulf, as determined by drift bottle studies, has been described by Bumpus and Lauzier (1965) and is depicted in figures 6 through 9. Water enters across Browns Bank, passes through the Bay of Fundy, flows southwest along the Maine coast, and leaves the Gulf through Great South Channel and across Georges Bank.

Eddies are formed offshore between the indraft water and the southwesterly flowing coastal water. In winter there are several irregular eddies present. In spring, runoff from rivers activates a large cyclonic gyre that grows to occupy the entire Gulf. This gyre slows down, persists through the summer and, in the autumn, decays northward.

Winds do not appear to have an important effect on the gross circulation of the Gulf. In summer, the prevailing south and southwest winds tend to reinforce the cyclonic circulation. The prevailing wind in winter is northwest, aiding the southerly drift along the west side of the basin, but the northward current along the eastern part of the basin opposes this wind. Close to shore, the local effects of winds may be more evident in the surface waters. The frequency of wind direction, by speed, is given in table 2.

During its southwesterly passage, the water of the coastal drift actually flows along the coastline and enters coastal estuaries. Consequently, the effluent waters from a power plant carried in this current can be expected to impinge upon the coast and to enter estuaries. As determined by seabed drifters (Graham, 1970), bottom water moves (1) shoreward and into bays and estuaries, or (2) along the coast for varying distances. This shoreward drift is in compensation for the outflow of surface water from the estuaries.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BAY OF FUNDY
GEORGES BANK
NOVA SCOTIA
BROWNS BANK

Figure 6. Circulation of the Gulf of Maine -- Winter (from Bumpus and Lauzier, 1965)

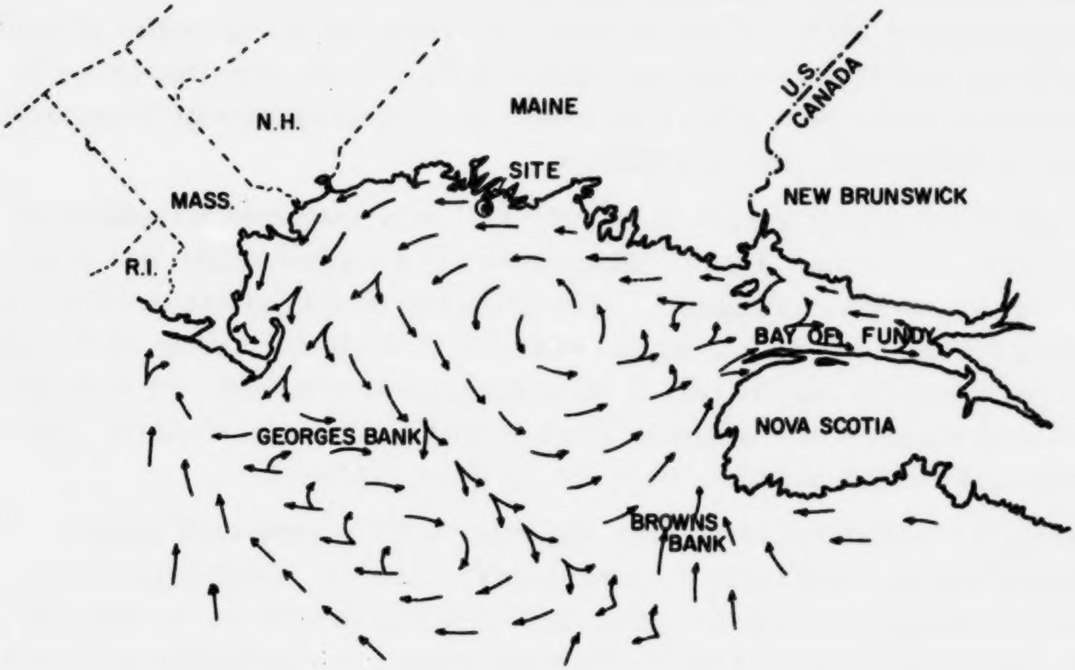
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Figure 7. Circulation of the Gulf of Maine -- Spring (from Bumpus and Lauzier, 1965)

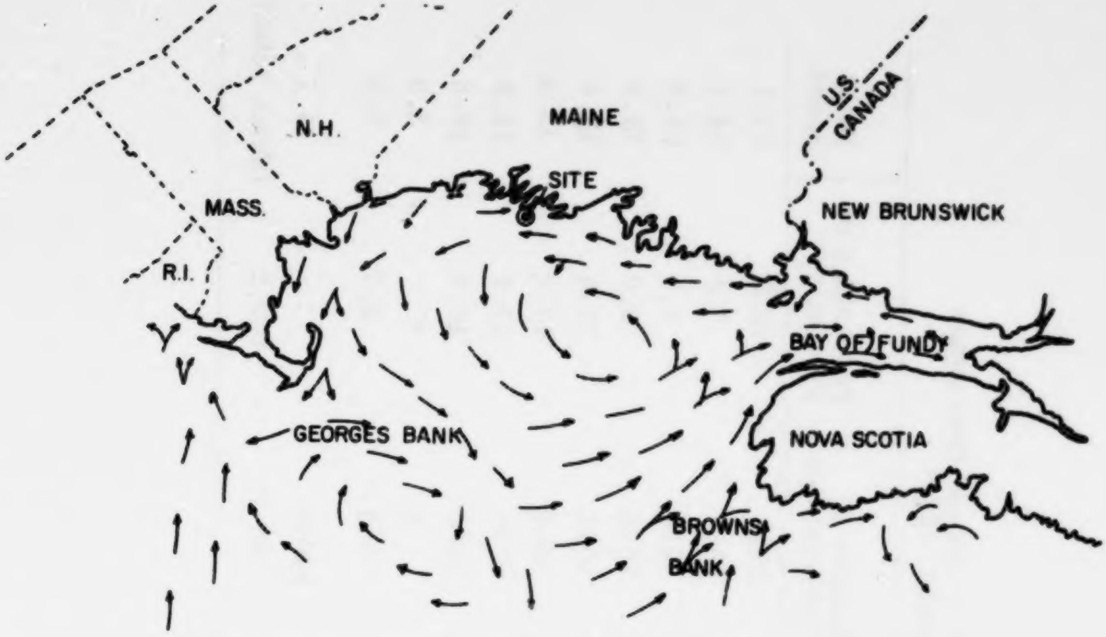
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Figure 8. Circulation of the Gulf of Maine -- Summer (from Bumpus and Lauzier, 1965)

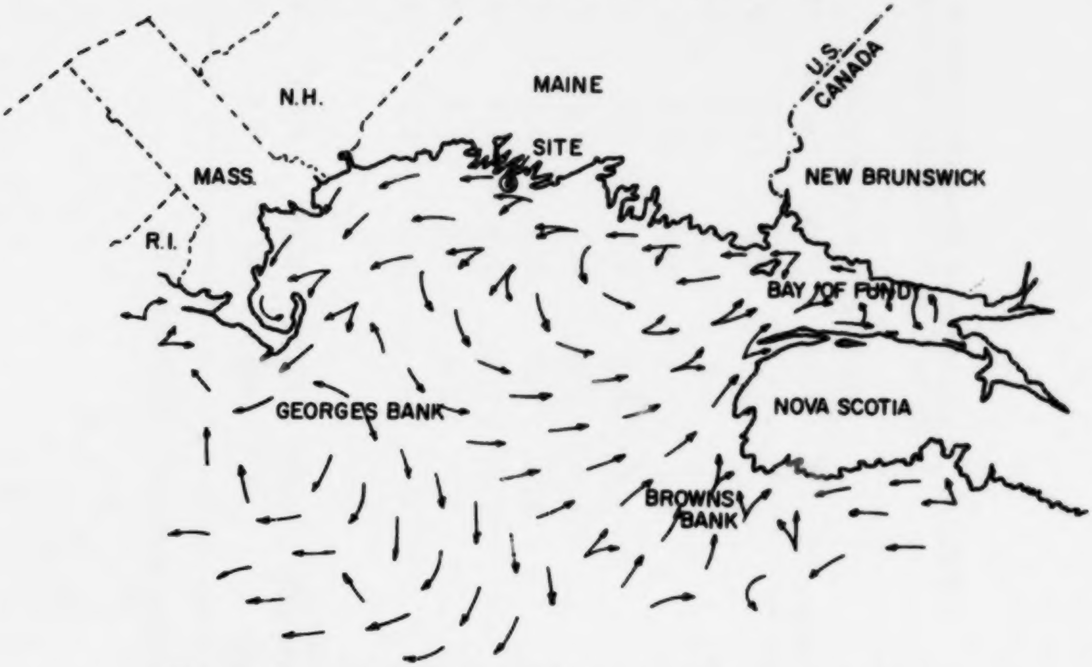
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Figure 9. Circulation of the Gulf of Maine -- Fall (from Bumpus and Lauzier, 1965)

Table 2. Frequency of Wind Direction by Speed -- Annual Percentage (from U.S.N. Weather Service Command, 1970)

Wind Direction	Wind Velocities (knots)					Number of Observations	Percentage of Frequency	Mean Speed
	0-6	7-16	17-27	28-40	41+			
N	1.7	4.8	2.8	0.8	0.1	3024	10.2	15.1
NE	1.4	3.6	1.8	0.5	0.1	2169	7.3	14.4
E	1.6	3.2	1.3	0.5	0.1	1974	6.7	13.5
SE	1.6	4.2	1.7	0.3	0.1	2375	8.0	13.0
S	2.8	9.0	4.1	0.6	*	4915	16.6	13.4
SW	2.7	9.9	4.4	0.8	0.1	5269	17.8	13.8
W	2.4	7.9	4.9	1.7	0.2	5070	17.1	15.9
NW	1.6	5.8	4.4	1.5	0.2	3990	13.5	16.8
Variable	*	*	0.0	0.0	0.0	9	*	2.9
Calm	2.7					784	2.7	0.0
Number of Observations	5469	14348	7500	2020	242	29579		14.2
Percentage	18.5	48.5	25.4	6.8	0.8	100.0	100.0	(Mean Total)

*Frequencies between 0.0% and 0.05%

At the proposed site area, bottom water may enter Muscongus Bay, Johns Bay, or the Damariscotta River -- or it may drift along the coast, perhaps entering other bays and estuaries. Through upwelling, this water will eventually be found at the surface along the coast and in the estuaries. The rate of drift ranges from 0.05 to 0.30 nm/day. The observed ratio of bottom drift to surface drift is 0.03 to 0.19 (Graham, 1970).

At the surface, the current trends to the southwest as described. However, combinations of factors such as wind conditions, dynamic topography, bottom topography, and the shoreline shape make surface coastal waters move shoreward. Figure 10 shows the routes inferred from drift bottle studies along coastal Maine. This pattern appears to persist throughout the year except in winter, when surface drift is offshore due to a combination of wind conditions and reduced outflow from the rivers.

Between the eddy-type circulation and the shore, a zone perhaps 14 nm wide, is the coastal drift, a southwesterly current that persists throughout the year. Effluent water from the underwater power plant will be dumped in the coastal drift water and can be expected to flow southwest along the coast at an average rate of 1.62 nm/day, ranging from 0.54 to 9.72 nm/day (Graham, 1970). This water either passes out of the Gulf into the Atlantic by way of Great South Channel or Georges Bank, or becoming entrained in an offshore eddy, is transported into the Bay of Fundy and eventually back along the Maine Coast. The latter track is the more probable when the cyclonic gyre is most developed, during spring and summer.

Tidal currents on the bottom in the site area will be low (less than 0.2 knot) due to the rapidly shoaling topography. However, near the surface, tidal currents can average 0.5 knot and reach 1.0 knot under extreme conditions, depending upon wind conditions.

Table 2 shows the annual wind conditions in the Gulf of Maine. Winds from the southwest to southeast tend to move surface waters offshore and to the northeast. When winds are from the west and north, the surface waters are moved to the southwest and onshore. (Note that surface currents are deflected as much as 45^{o} to the right of the wind direction by the coriolis force.)

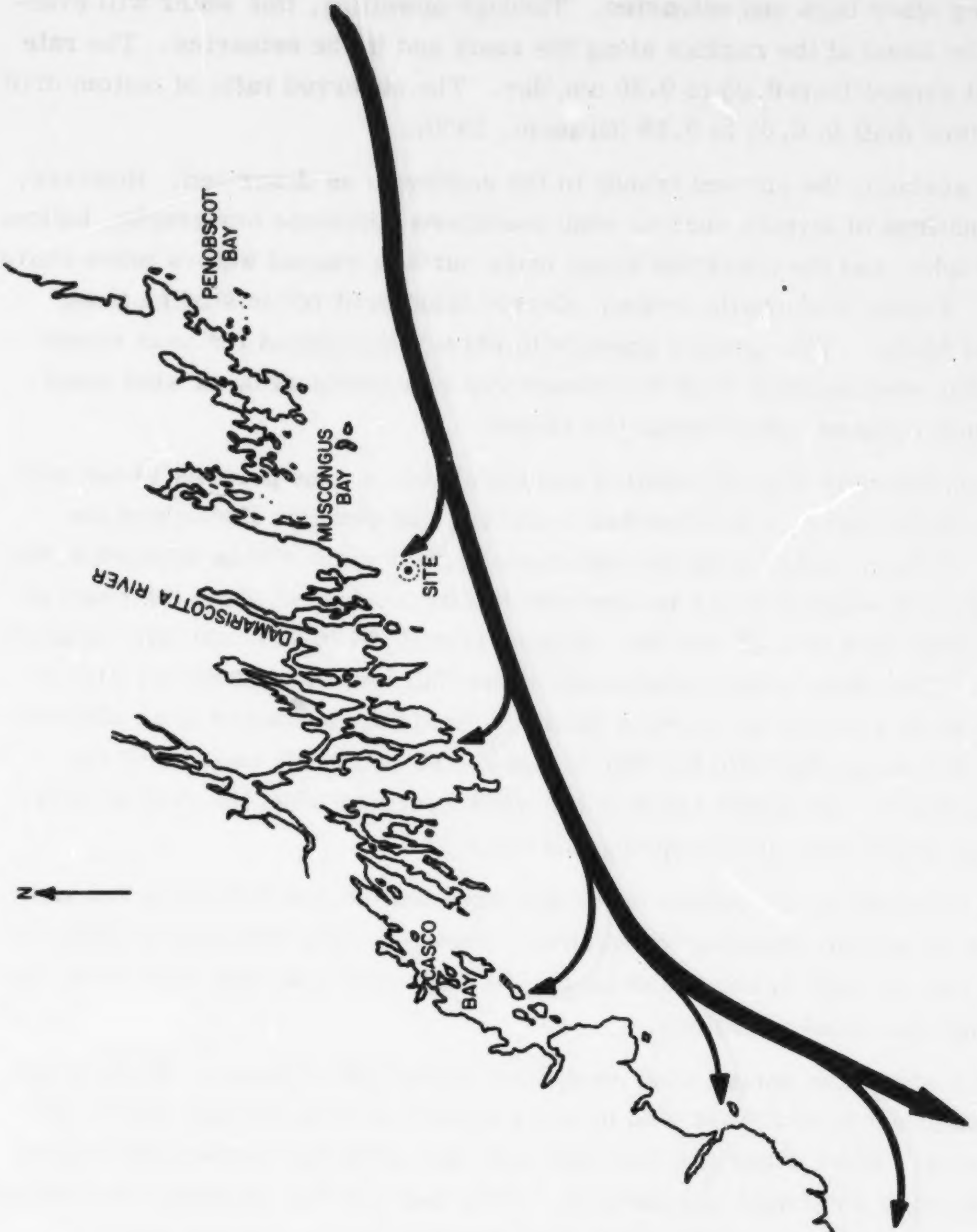
PENOBSCOT BAY
MUSCONGUS BAY
SITE
DAMARISCOTTA RIVER
CASCO BAY
N

Figure 10. Surface Transportation of Water Particles along the Maine Coast (adapted from Graham, 1970)

Bottom Characteristics

The coastal Gulf of Maine east of Cape Elizabeth has a continuously rocky shoreline and deep bays following each other in close succession, a typical glacially eroded topography. The near shore bottom is rocky and irregular, bedrock being close to the surface. Fluviatile processes subsequent to the glacial period have tended to modify the original topography, shallow water sediments being reworked so that the fine fraction is winnowed out by waves and currents and deposited in deeper water. In the general site area, the shallows or topographic highs are either bedrock and bedrock thinly covered with sand, or gravel (Ostericher, 1965). The depressions or deep areas, where the proposed site would be, contain fine grained sediments, mixtures of silt and clay. Samples taken by Ostericher in a similar area and in similar depths off the mouth of Penobscot Bay, about 20 nm east of the site area, ranged from pebbly sands to silty muds. Median diameters of the finer sediments ranged from 0.03 to 0.004 mm. Subbottom profiling traverses over these sample areas indicated that the thickness of the sediment accumulation over bedrock in the deep areas is small, perhaps on the order of 20-30 ft. Thus, from a foundation engineering viewpoint, although sediments may be weak, pilings to bedrock should be feasible.

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BIOLOGICAL DESCRIPTION (Wiscasset Area)

Ecology

The Wiscassett, Maine region is distinguished by a highly irregular, rocky coast, a wide continental shelf, and offshore banks (submerged plateaus) that support some of the major commercial fisheries of the world. Water circulation generally characterized by a huge counterclockwise eddy, and the bottom topography of the Gulf of Maine, serves to contain the productive waters within the Gulf for extended periods of time. A euphotic zone of at most 50 meters in this region contrasts sharply with that of 100 meters or more in the Florida Straits. This history of oceanography in the Gulf of Maine is reviewed by Colton (1964).

Biologically, the waters are characterized by strong seasonal pulses in the abundance of phytoplankton and zooplankton. Peak abundance of phytoplankton occurs primarily in the spring and to a lesser extent in the late summer or fall. The phytoplankton are generally dominated by diatoms except during the summer. Peak abundances of phytoplankton are soon followed by peak abundances of grazing zooplankton, dominated by copepods, which persist throughout the year. However, during the spring or summer meroplanktonic organisms often constitute a significant fraction of the zooplankton volume.

Food chain relationships in the Gulf are believed to be based on the photosynthetic capabilities of the diatoms and other phytoplankton (see figure 11). It is reasonable to assume that inorganic nutrients to support growth of diatoms are generated locally in the region, where they occur with a significant land and estuarine contribution by rivers discharging into the Gulf. The primary herbivores feeding on the diatoms are copepods which, in turn, are consumed by carnivores such as fish larvae and other carnivorous zooplankton. Other animals that feed on the phytoplankton include forage fish, bottom filter feeders, and attached organisms. These, in their turn, are preyed upon by secondary carnivores. Some organisms attached to firm substrates, or dwelling in or on the bottom, specialize in consuming the energy-containing residues resulting from the carnage occurring in the water column. The net effect is the production of nutrients available to plants, which permits another cycle.

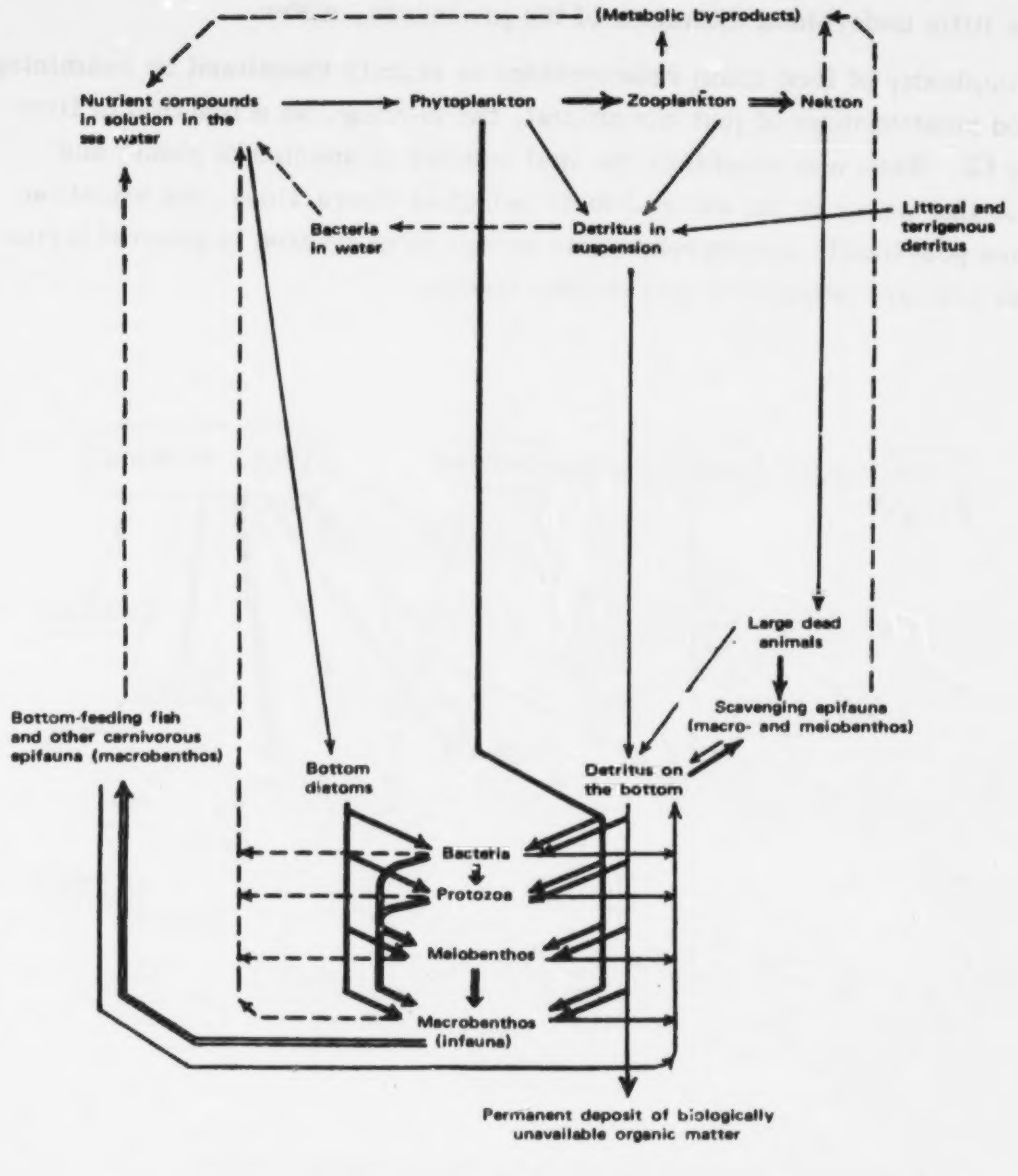

(Metabolic by-products)
Nutrient compounds in solution in the sea water
Phytoplankton
Zooplankton
Nekton
Bacteria in water
Detritus in suspension
Littoral and terrigenous detritus
Large dead animals
Scavenging epifauna (macro- and meiobenthos)
Bottom-feeding fish and other carnivorous epifauna (macrobenthos)
Bottom diatoms
Detritus on the bottom
Bacteria
Protozoa
Meiobenthos
Macrobenthos (infauna)
Permanent deposit of biologically unavailable organic matter

Figure 11. Main Phases of Marine Food Cycle (from Mare, 1942). Phases occurring in the water are in upper part of diagram; in lower part are those occurring at bottom surface and in bottom deposit.

From the brief discussion above, it is apparent that food chain relationships in boreal and tropical waters are basically similar when reduced to the simplest terms possible. However, the species of plants and animals involved, and the little understood dynamics of the processes, differ.

The complexity of food chain relationships is readily visualized by examining the food relationships of just one animal, the herring, as a function of time (figure 12). When one considers the vast number of species of plants and animals that occur in the sea and their potential interactions, the situation becomes practically incomprehensible except when treated in general terms such as primary production and trophic levels.

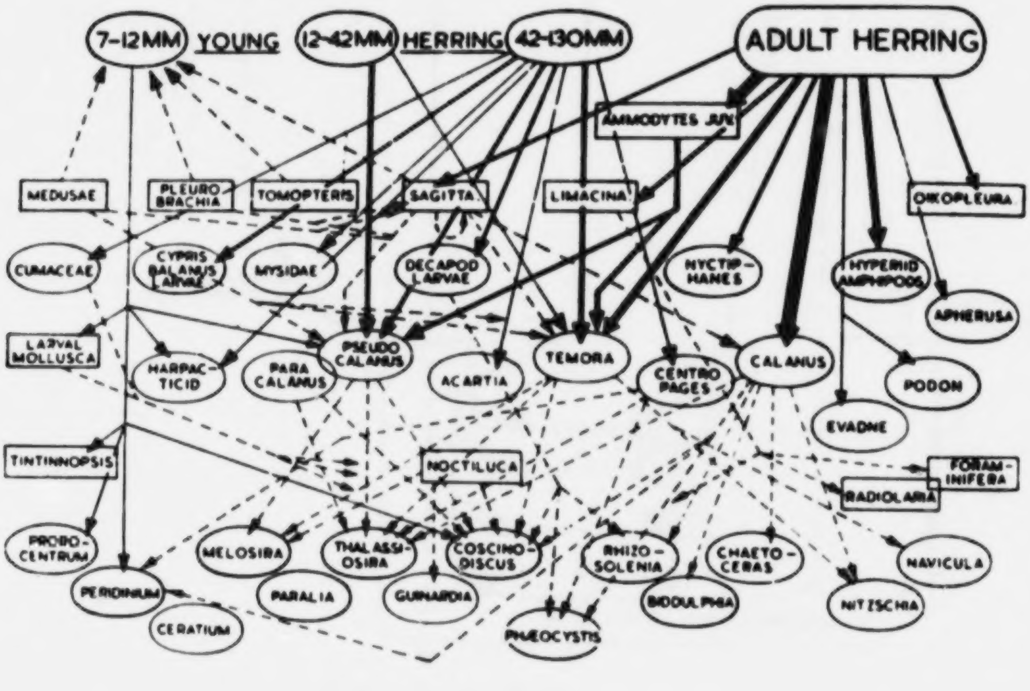

7-12MM
YOUNG
12-42MM
HERRING
42-130MM
ADULT HERRING
AMMODYTES JUV.
MEDUSAE
PLEURO BRACHIA
TOMOPTERIS
SAGITTA
LIMACINA
OIKOPLEURA
CUMACEAE
CYPRIS BALANUS LARVAE
MYSIDAE
DECAPOD LARVAE
NYCTIPHANES
HYPERIID AMPHIPODS
APHERUSA
LARVAL MOLLUSCA
HARPACTICID
PARA CALANUS
PSEUDO CALANUS
ACARTIA
TEMORA
CENTRO PAGES
CALANUS
PODON
EVADNE
TINTINNOPSIS
NOCTILUCA
FORAMINIFERA
RADIOLARIA
PRORO-CENTRUM
MELOSIRA
THALASSIOSIRA
COSCINODISCUS
RHIZOSOLENIA
CHAETOCERAS
NAVICULA
PERIDINIUM
PARALIA
GUINARDIA
BIDDULPHIA
NITZSCHIA
CERATIUM
PHAEOCYSTIS

Figure 12. Food of the Herring (from Hardy, 1924)

Phytoplankton

Other than the work of Stickney (1959), there has been little information published on the phytoplankton in the immediate offshore region of Wiscassett, Maine. However, the seasonal and spatial distribution of phytoplankton in the Gulf of Maine has been studied by a number of workers for many years: Bigelow (1926), Gran and Braarud (1935), Bigelow et al (1940), Lillick (1940), Sears (1941), and Riley and Bumpus (1946). Although perhaps not applicable in every detail, the above work should be generally indicative of the situation in the region of Wiscassett.

A generalized scheme of the seasonal cycle of phytoplankton, based on observed and calculated cycles, is given in figure 13. The figure shows that phytoplankton reach a peak abundance in the spring, followed by a lower but secondary peak abundance in the summer. The euphotic zone can be considered to extend to a maximum depth of 50 meters as a first approximation. According to Lillick (1940) the winter flora in the western basin of the Gulf of Maine is usually dominated by *Coscinodiscus*, a diatom, and coccolithophores (see figure 14). *Chaetoceros convolutus*, *Ch. decipiens*, *Ch. atlanticus*, and *Thalassiosira decipiens* are most abundant during the spring diatom outburst. During the summer, the phytoplankton consist of a mixture of peridinians, especially *Ceratium*, coccolithophores, and a mixture of neritic diatoms which may flower in later summer or early fall. Finally, the diverse mixture of species in the early fall is succeeded by a much reduced flora of *Coscinodiscus* and peridinians in the late fall. The actual succession of species in various regions of the Gulf differs somewhat as shown in figure 15. For example, in the western coastal waters and Georges Bank, *Skeletonema* and *Rhizosolenia* are often prominent in addition to *Coscinodiscus*. Furthermore, neritic diatoms are prominent in later spring in addition to *Chaetoceros* species.

Stickney (1959) states that diatoms of several species, chiefly of the genera *Thalassiosira*, *Thalassiothrix*, and *Chaetoceros* appear in the spring at the mouth of the Sheepscot Estuary. *Skeletonema*, *Asterionella*, and *Rhizosolenia* appear during the summer, and several species of *Coscinodiscus* are present year round. The dinoflagellates most abundant include *Ceratium tripos*, *C. longipes*, and *C. fusus*, with several species of *Peridinium* also common.

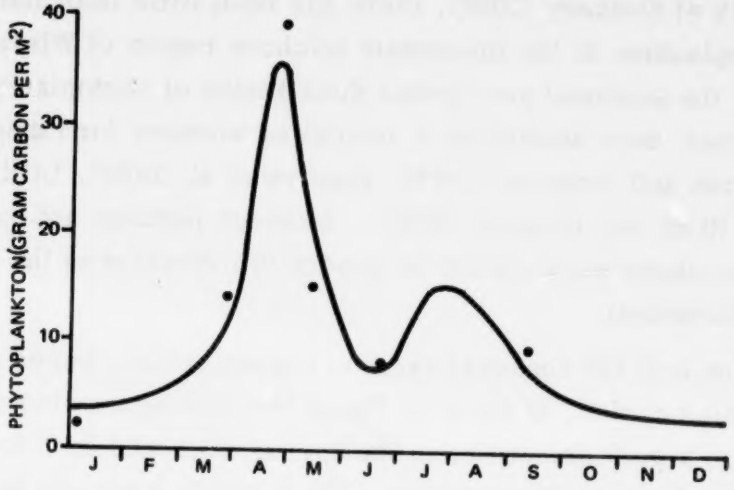


Figure 13. Calculated Seasonal Cycle of Phytoplankton (from Riley, 1947). Values have been determined by approximate integration of the equation for rate of population change. Dots indicate observed quantities of phytoplankton.

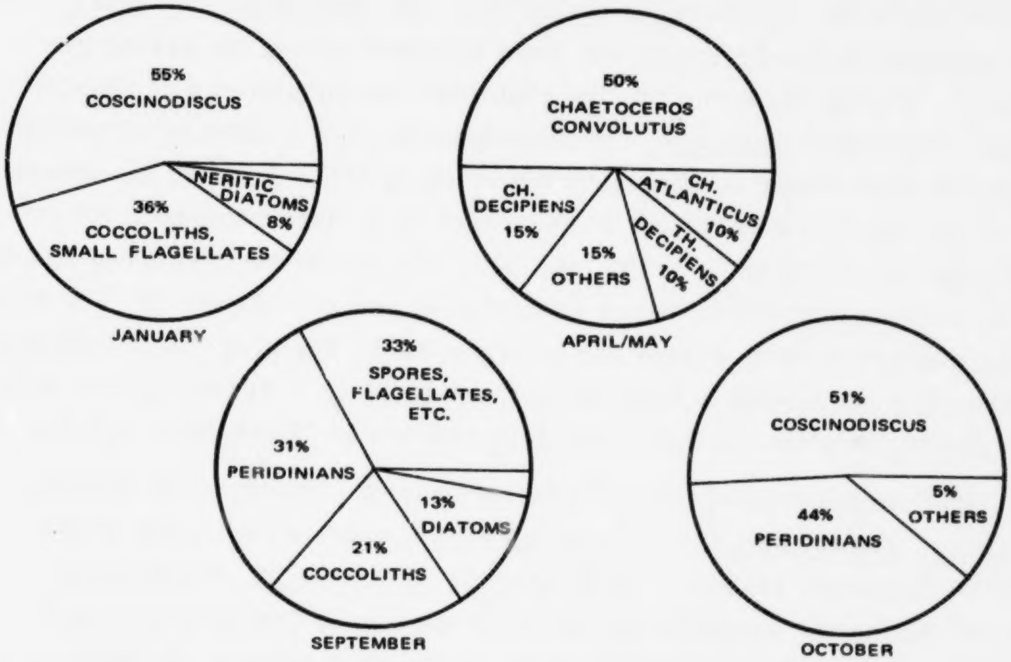


Figure 14. Percentage Composition, over Different Months, of Phytoplankton in Western Basin, Gulf of Maine (from Lillick, 1940 - modified)

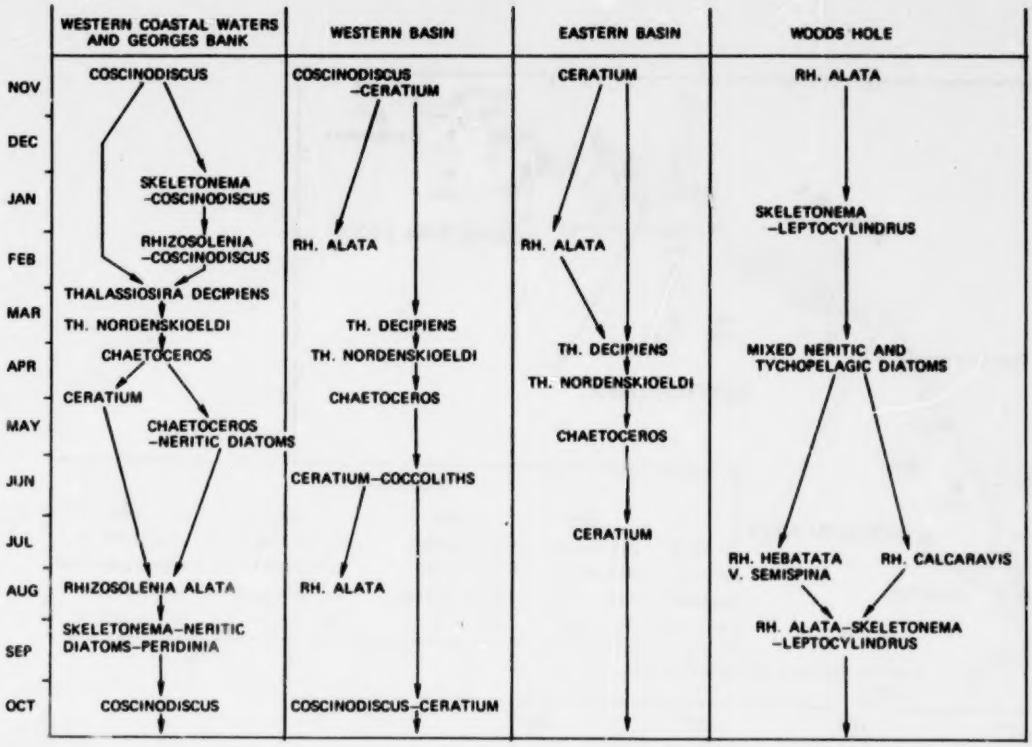
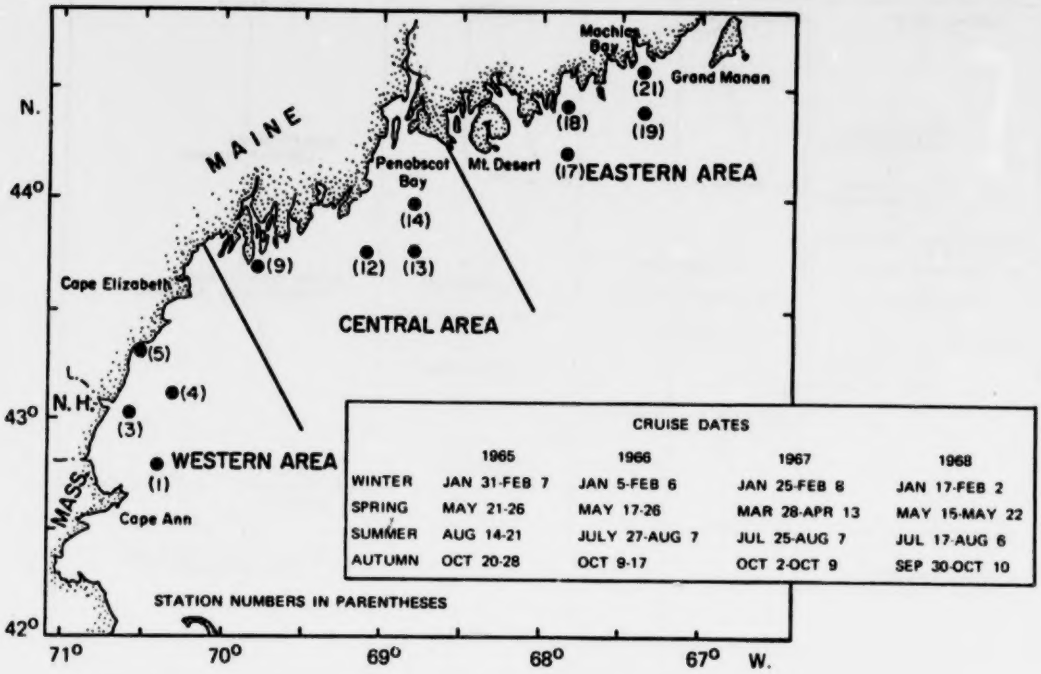

WESTERN COASTAL WATERS AND GEORGES BANK
WESTERN BASIN
EASTERN BASIN
WOODS HOLE
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
COSCINODISCUS
SKELETONEMA -COSCINODISCUS
RHIZOSOLENIA -COSCINODISCUS
THALASSIOSIRA DECIPIENS
TH. NORDENSKIOELDI
CHAETOCEROS
CERATIUM
CHAETOCEROS -NERITIC DIATOMS
RHIZOSOLENIA ALATA
SKELETONEMA-NERITIC DIATOMS-PERIDINIA
COSCINODISCUS
COSCINODISCUS -CERATIUM
RH. ALATA
TH. DECIPIENS
TH. NORDENSKIOELDI
CHAETOCEROS
CERATIUM-COCCOLITHS
RH. ALATA
COSCINODISCUS-CERATIUM
CERATIUM
RH. ALATA
TH. DECIPIENS
TH. NORDENSKIOELDI
CHAETOCEROS
CERATIUM
RH. ALATA
SKELETONEMA -LEPTOCYLINDRUS
MIXED NERITIC AND TYCHOPELAGIC DIATOMS
RH. HEBATATA V. SEMISPINA
RH. CALCARAVIS
RH. ALATA-SKELETONEMA -LEPTOCYLINDRUS

Figure 15. Seasonal Succession of Dominant Phytoplankton Species in Gulf of Maine Areas (from Lillick, 1940 - modified)

Margelef (1958) believes that the spring flowering of phytoplankton starts with small diatoms capable of rapid division, which are then succeeded by larger diatom species and finally dinoflagellates. Succession is believed to be controlled by nutrient concentration and external metabolites. Water temperature and light intensity also play an important role.

Zooplankton

Sherman of the Bureau of Commercial Fisheries (BCF) at Boothbay Harbor, Maine has been studying the zooplankton of the coastal waters of the Gulf of Maine since 1963 (Sherman, 1966a, 1966b, 1968, 1970). A map of his sampling stations is given in figure 16. The organisms obtained at station 9 (depth 67 m) is of particular interest to this study, but Sherman has generally treated


N.
44°
43°
42°
71°
70°
69°
68°
67°
W.
MAINE
N. H.
MASS.
Machias Bay
Grand Manan
Penobscot Bay
Mt. Desert
Cape Elizabeth
Cape Ann
(1)
(3)
(4)
(5)
(9)
(12)
(13)
(14)
(17)
(18)
(19)
(21)
EASTERN AREA
CENTRAL AREA
WESTERN AREA
STATION NUMBERS IN PARENTHESES

CRUISE DATES

	1965	1966	1967	1968
WINTER	JAN 31-FEB 7	JAN 5-FEB 6	JAN 25-FEB 8	JAN 17-FEB 2
SPRING	MAY 21-26	MAY 17-26	MAR 28-APR 13	MAY 15-MAY 22
SUMMER	AUG 14-21	JULY 27-AUG 7	JUL 25-AUG 7	JUL 17-AUG 6
AUTUMN	OCT 20-28	OCT 9-17	OCT 2-OCT 9	SEP 30-OCT 10

Figure 16. Zooplankton Sampling Stations, Gulf of Maine Coastal Waters (from Sherman, 1970)

his data by regions shown. One should also note that Sherman's data are essentially surface samples derived from composite, 10-min, step-oblique tows (0.336-mm screening) taken during the daytime, at the surface, 10 m and 20 m depths.

His data generally show that the mean annual volume of zooplankton is greatest for the western region of the Gulf of Maine and least in the eastern region as shown in figure 17. Considerable variations in mean seasonal zooplankton volumes occur from year to year and region to region as shown in figures 18 and 19. However, a compilation of mean volumes at station 9 over a 5-yr period show peak abundances in spring and fall and minimum volumes in the winter (table 3).

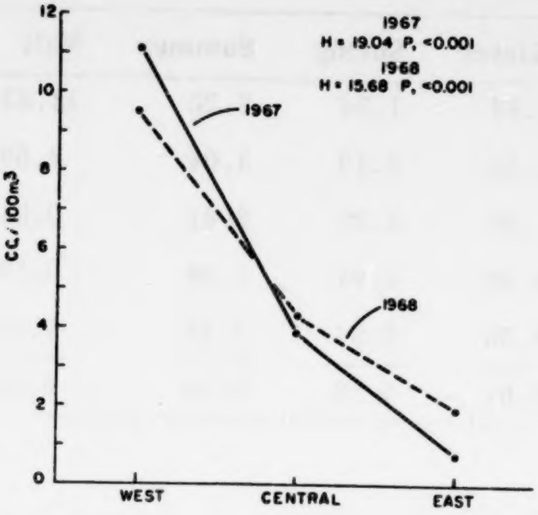


Figure 17. Mean Annual Volumes of Zooplankton for Gulf of Maine Coastal Waters in Areas Investigated, 1967 and 1968 (from Sherman, 1970)

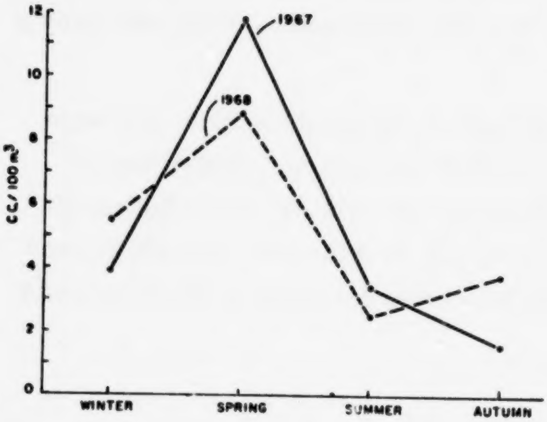


Figure 18. Mean Seasonal Volume of Zooplankton in Gulf of Maine Coastal Waters, 1967 and 1968 (from Sherman, 1970)

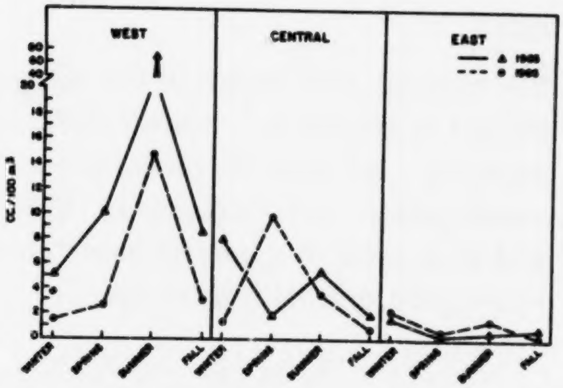


Figure 19. Mean Seasonal Volumes of Zooplankton in Gulf of Maine Coastal Waters, 1965 and 1966 (from Sherman, 1968)

Table 3. Zooplankton Sample Volumes (cc/100 m^3) at Station 9 (adapted from Sherman, 1966, 1968, 1970)

Year	Winter	Spring	Summer	Fall
1964	1.34	1.94	5.78	13.48
1965	1.55	2.17	3.04	4.57
1966	1.04	3.83	2.41	0.91
1967	0.57	9.91	1.26	0.19
1968	0.55	8.94	4.22	6.43
Mean	1.01	5.36	3.34	5.11

Riley (1947) performed a theoretical analysis of the zooplankton of Georges Bank. His mathematically derived population curve, calculated on the basis of seasonal variation in environmental factors, agrees very well with the observed population curves based on measurements.

The copepods dominate the zooplankton during all seasons as shown in figures 20 and 21 and tables 4 through 7. During the spring and summer, the holoplanktonic Euphausiacea, Appendicularia, and Cladocera may constitute a significant fraction of the zooplankton. This also applies for meroplanktonic fish and crustacean eggs. Cirripedea larvae are prominent during the spring only.

The vertical distribution of the various groups of zooplankton has not been studied in any detail. Clarke (1934) has worked with diurnal migration of copepods, and Sherman and Schaner (1968) with the vertical distribution of chaetognaths. For purposes of this study, it can be assumed that all groups will be present at the depth under consideration and all holoplanktonic groups will exhibit diurnal migrations.

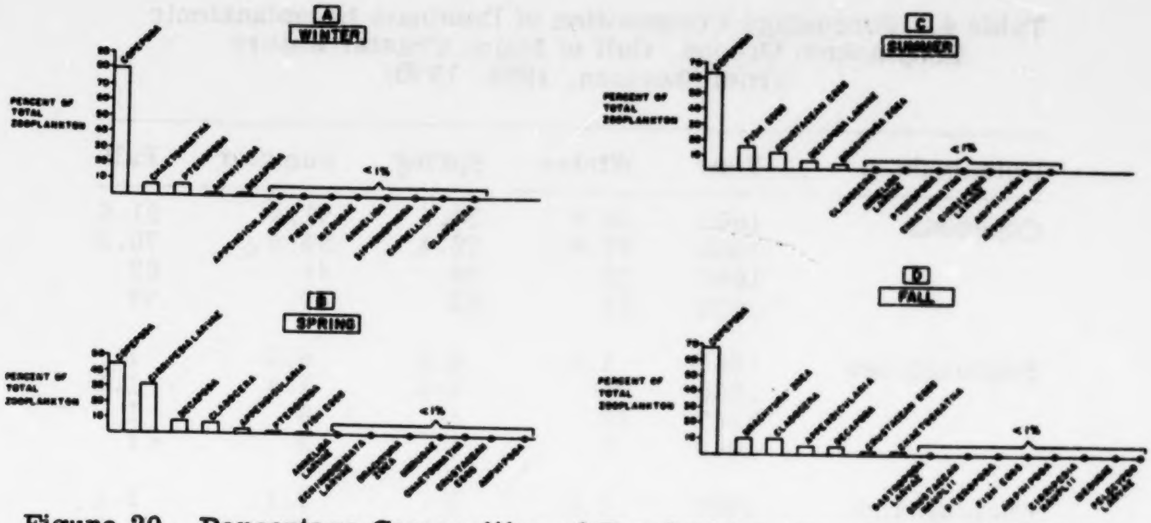


Figure 20. Percentage Composition of Zooplankton Groups in Gulf of Maine by Season in 1964 (from Sherman, 1966)

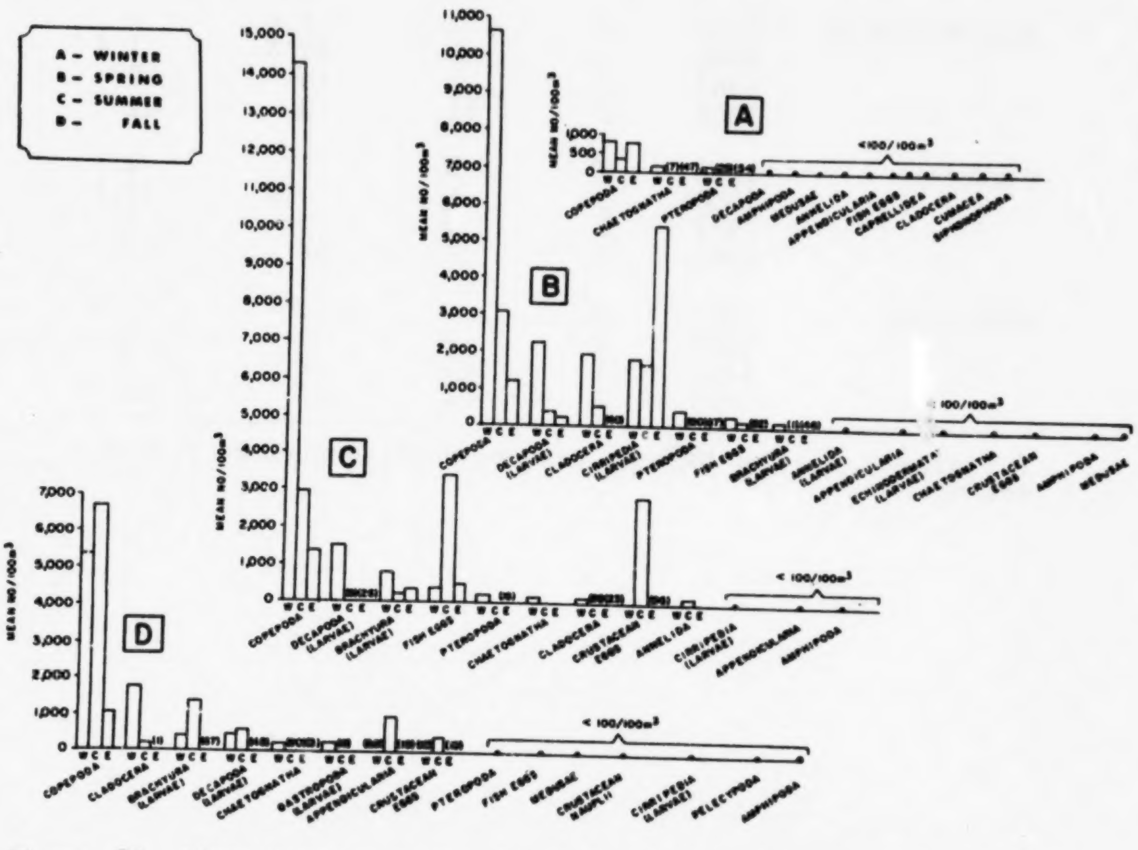


Figure 21. Mean Number of Dominant Zooplankton Groups per 100 m^3 of Water in Gulf of Maine by Season in 1964 - Western (W), Central (C), Eastern (E) (from Sherman, 1966)

Table 4. Percentage Composition of Dominant Holoplanktonic Zooplankton Groups, Gulf of Maine Coastal Waters (from Sherman, 1968, 1970)

Holoplankton	Year	Winter	Spring	Summer	Fall
Copepoda	1965	96.9	74.4	71.4	91.6
	1966	97.3	72.4	35.4	76.8
	1967	73	78	41	62
	1968	98	62	47	72
Euphausiacea	1965	1.3	4.6	6.2	P
	1966	P	4.6	3.4	1.5
	1967	10	1	8	1
	1968	0	1	2	<1
Chaetognatha	1965	1.3	P	1.1	2.1
	1966	1.9	--	P	1.5
	1967	3	<1	<1	2
	1968	<1	<1	<1	<1
Appendicularia	1965	--	2.1	1.6	P
	1966	--	3.7	27.4	1.4
	1967	7	0	14	2
	1968	0	21	12	<1
Cladocera	1965	P	2.6	P	2.1
	1966	P	1.6	1.9	12.1
	1967	2	0	7	9
	1968	0	4	14	13
Pteropoda	1965	P	--	P	1.0
	1966	P	P	P	P
	1967	<1	<1	0	0
	1968	2	<1	<1	<1

P = present, but less than one percent of the zooplankton in each season.

Table 5. Percentage Composition of Dominant Meroplanktonic Zooplankton Groups, Gulf of Maine Coastal Waters (from Sherman, 1968, 1970)

Meroplankton	Year	Winter	Spring	Summer	Fall
Fish eggs	1965	P	1.1	6.1	P
	1966	P	1.7	8.1	P
	1967	2	<1	19	<1
	1968	<1	<1	4	2
Crustacean eggs	1965	--	P	10.9	P
	1966	P	13.3	P	--
	1967	0	<1	6	16
	1968	0	<1	9	<1
Cirripedia larvae	1965	P	12.3	P	--
	1966	P	13.3	P	--
	1967	<1	14	<1	<1
	1968	0	5	2	0
Decapoda larvae	1965	P	P	P	P
	1966	--	P	4.8	P
	1967	2	4	<1	<1
	1968	0	5	3	1
Brachyura larvae	1965	--	P	1.5	1.4
	1966	--	P	1.8	--
	1967	<1	<1	2	3
	1968	0	<1	1	1

P = present, but less than one percent of the zooplankton in each season.

Table 6. Mean Numbers of Dominant Holoplanktonic Zooplankton Groups per 100 m^3 of Water by Season, Gulf of Maine Coastal Waters (from Sherman, 1968, 1970)

Holoplankton	Year	Winter	Spring	Summer	Fall
Copepoda	1965	2,496	5,733	26,008	20,397
	1966	1,233	7,058	8,725	3,664
	1967	322	4,645	4,228	2,802
	1968	3,710	23,829	5,434	3,306
Mean		1,940	10,316	11,099	7,542
Euphausiacea	1965	31	353	2,259	45
	1966	3	444	846	72
	1967	42	84	797	47
	1968	0	412	186	32
Mean		19	323	1,022	49
Chaetognatha	1965	34	13	380	157
	1966	24	1	81	70
	1967	14	14	26	81
	1968	11	16	11	3
Mean		21	11	125	78
Appendicularia	1965	--	164	598	15
	1966	--	363	6,755	67
	1967	30	0	1,441	90
	1968	0	7,960	1,323	30
Mean		15	2,122	2,529	51
Cladocera	1965	1	203	113	157
	1966	2	155	467	579
	1967	7	0	723	411
	1968	0	1,484	1,608	617
Mean		3	461	728	441
Pteropoda	1965	5	--	9	66
	1966	1	15	2	1
	1967	<1	3	0	0
	1968	62	232	39	37
Mean		17	83	13	26

Table 7. Mean Numbers of Dominant Meroplanktonic Groups per 100 m^3 of Water by Season, Gulf of Maine Coastal Waters (from Sherman, 1968, 1970)

Meroplankton	Year	Winter	Spring	Summer	Fall
Fish eggs	1965	5	146	2,210	25
	1966	1	163	1,993	7
	1967	8	18	1,928	17
	1968	4	298	479	104
Mean		5	156	1,653	38
Crustacea eggs	1965	--	1	4,004	25
	1966	1	84	3,717	166
	1967	0	32	576	755
	1968	0	145	1,023	6
Mean		<1	66	2,330	238
Cirripedia larvae	1965	--	949	31	--
	1966	1	1,295	129	--
	1967	3	842	29	4
	1968	0	2,026	226	0
Mean		1	1,278	104	1
Decapoda larvae	1965	2	41	201	35
	1966	--	61	1,184	21
	1967	9	211	49	25
	1968	0	1,856	318	57
Mean		3	542	438	35
Brachyura larvae	1965	--	19	543	107
	1966	--	55	452	60
	1967	<1	47	186	149
	1968	0	19	149	53
Mean		<1	35	333	92

Copepods

The dominant Copepoda present in the Gulf of Maine are *Calanus finmarchicus* and *Centropages typicus* as shown in figure 22 and table 8. Other prominent species include *Pseudocalanus minutus*, *Centropages hamatus*, and *Temora longicornis*.

The diurnal migration of *Calanus finmarchicus* is shown in figure 23. This copepod apparently can migrate about 80 m at locations with sufficient depth.

Sherman and Honey (1970) studied the diurnal distribution of zooplankton in coastal waters at Boothbay Harbor having a depth of 33-35 m. They observed that *Pseudocalanus minutus* was generally concentrated near the bottom during daylight, rose to the surface in late afternoon, and descended to 30 m after sunset. *Calanus finmarchicus*, by contrast, exhibited very complex movements.

Other Zooplankton Groups

In addition to the copepods, Sherman and Honey (1970) observed the vertical distribution of the chaetognath (*Sagitta elegans*), larval decapods, and larval cirripeds. At this 35-m deep station, *Sagitta elegans* essentially remained at the bottom with some migration upward in the evening (figure 24). Larval decapods were concentrated at 10 m during the day and moved to the surface after sunset, while the distribution of larval cirripeds was highly variable.

In a winter study, Sherman and Schaner (1968) found *Sagitta elegans* to depths of 60 m, the maximum depth at which tows were made, with indications of greatest numbers at a depth of 10 m (figure 25).

Principal Fisheries

The most important commercial fisheries to the economy of Maine are given in table 9. Interestingly, although the Gulf of Maine is world famous for its fisheries, the invertebrate fisheries account for approximately 80% of the dollar value of Maine landings. Of the wide variety of fish available, only ocean perch, sea herring, and whiting are brought into Maine ports in major quantities. In terms of international landings in tons for 1968, recorded by International Commission for the Northwest Atlantic Fisheries (ICNAF, 1970),

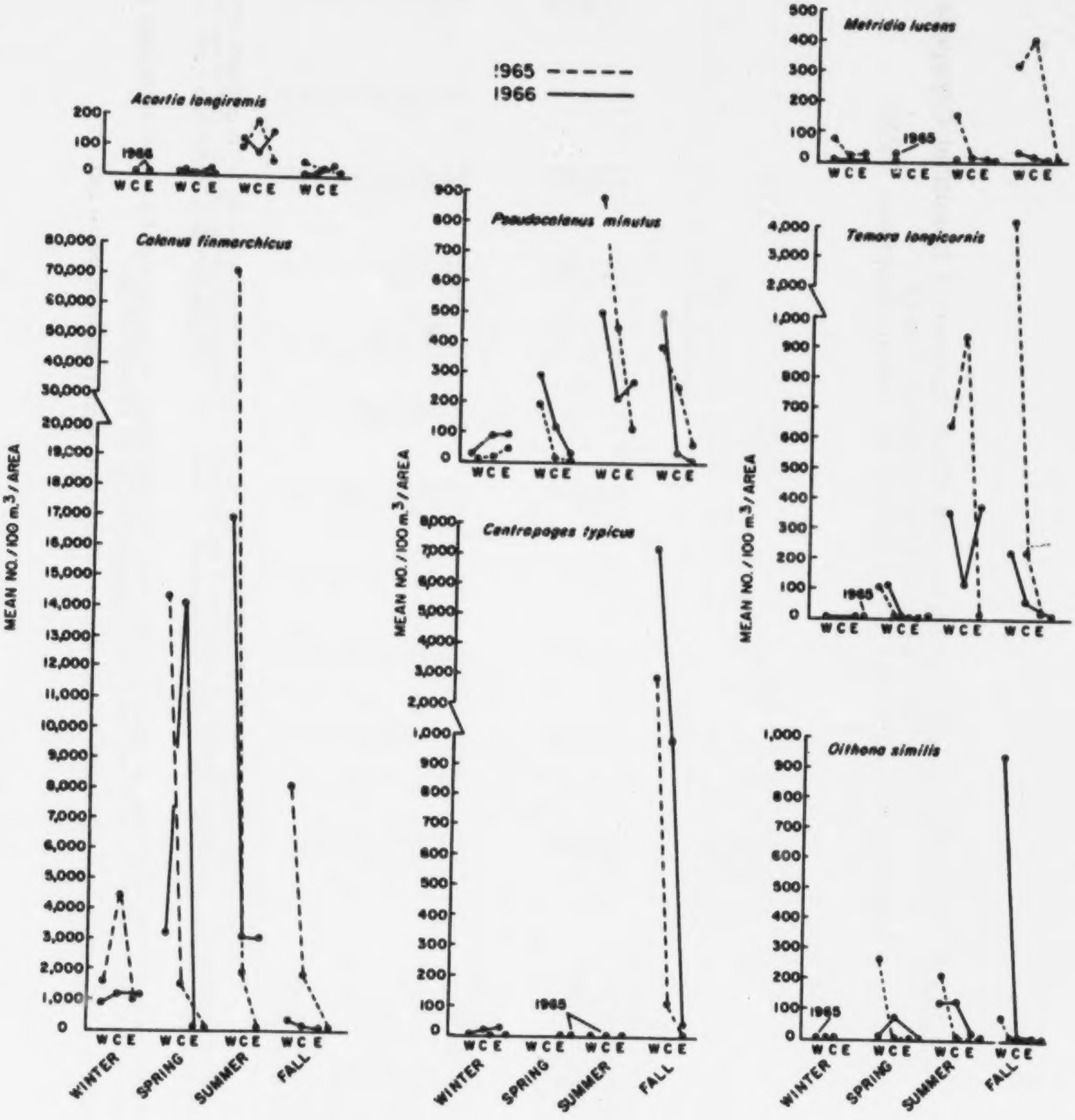


Figure 22. Mean Number of Dominant Copepod Species per m^3 of Water in Gulf of Maine Areas - Western (W), Central (C), Eastern (E) - in 1965 and 1966 (from Sherman, 1968)

Table 8. Total Species Composition and Mean Number of Dominant Copepods per m^3 of Water in Gulf of Maine Areas -- Western (W), Central (C), Eastern (E) (from Sherman, 1970)

Year and Species	Mean Number/ Station	Winter			Spring			Summer			Autumn		
		W	C	E	W	C	E	W	C	E	W	C	E
		Number/100 m^3											
1967:													
Common species (>50/100 m^3)*													
Calanus finmarchicus	2,010	330	322	148	10,543	2,985	226	5,528	1,565	1,309	518	217	10
Centropages typicus	500	2	35	23	0	0	0	62	105	0	5,377	274	12
Pseudocalanus minutus	94	13	6	7	133	7	19	1,616	395	178	394	277	53
Temora longicornis	85	11	2	1	2	0	0	400	324	4	159	89	5
Oithona spp.	50	18	4	5	0	0	<1	137	40	7	362	17	5
1968:													
Common species (>50/100 m^3)**													
Calanus finmarchicus	7,127	4,891	2,627	2,561	59,295	5,207	152	2,256	1,069	2,274	700	823	217
Centropages typicus	3,832	0	3	84	91	0	<1	2,413	79	72	26,170	14,634	1,055
Centropages hamatus	1,468	0	0	0	475	33	0	144	596	64	1,489	2,338	133+
Pseudocalanus minutus	763	16	39	38	1,247	246	23	1,114	504	1,451	21	77	51+
Temora longicornis	644	17	<1	0	913	18	2	635	763	625	137	657	120+
Acartia longiremis	153	0	0	6	342	240	6	0	351	80	15	18	25+
Calanoid spp. (immature)	152	0	0	0	1,538	42	0	0	154	9	0	0	0
Oithona spp.	134	14	0	0	1,210	1	<1	0	33	5	174	100	5
Acartia clausii	89	0	0	0	0	0	1	0	93	13	23	25	16+
Eurytemora herdmani	78	0	0	0	89	0	0	5	760	42	0	0	9
Tortanus discaudatus	71	0	0	0	244	56	0	14	22	181	117	106	160

*Less numerous species (<50/100 m^3) and number/100m^3, in 1967, were: *Acartia longiremis*, 34; *Metridia lucens*, 29; *Eurytemora herdmani*, 21; *Acartia clausi*, 14; *Centropages hamatus*, 14; *Tortanus discaudatus*, 6; Calanoid spp.(immature), 3; and *Paracalanus parvus*, 2. Species representing a mean of less than 1 per season in each area were *Metridia longa*, *Acartia* spp.(immature), Cyclopoid spp., *Euchaeta norvegica*, Harpacticoid spp., and *Anomalocera pattersoni*.

**Less numerous species (<50/100 m^3) and number/100 m^3, in 1968, were: *Metridia lucens*, 41; *Acartia* spp. (immature), 11; *Metridia longa*, 3. Species representing a mean of less than 1 per season in each area were *Euchaeta norvegica* and Harpacticoid spp.

+Values adjusted to Gulf III equivalents for the smaller copepod species collected in the bongo samplers in autumn 1968.

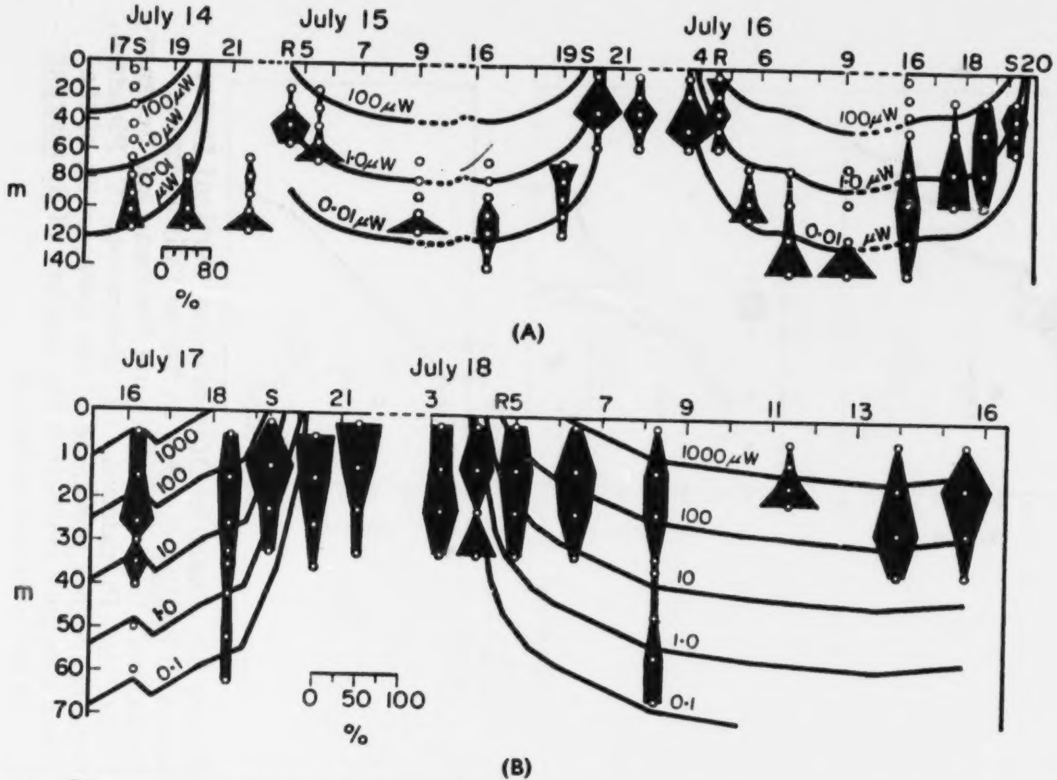


Figure 23. Comparison of Diurnal Migration of Calanus at Two Stations in Gulf of Maine -- (A) Deep Station, (B) Bank Station (from Clarke, 1934). Changes in intensity of blue component of daylight are presented in $\mu W/cm^2$– sunset (S), sunrise (R). Broken lines represent shortening of time scale: observations are not discontinued.

Table 9. Summary of Landings at Maine Ports in 1969, Arranged by Dollar Value (from Maine landings, 1969)

Species	Weight (lb)	Value ($)
Lobster	19,834,780	16,046,829
Shrimp	24,235,340	3,044,948
Ocean perch	50,752,394	2,151,758
Clam meats (Mya)	4,134,918	1,752,149
Blood worms	782,002	999,787
Sea herring	54,213,635	967,657
Whiting	17,889,677	801,872
Sandworms	672,860	523,836

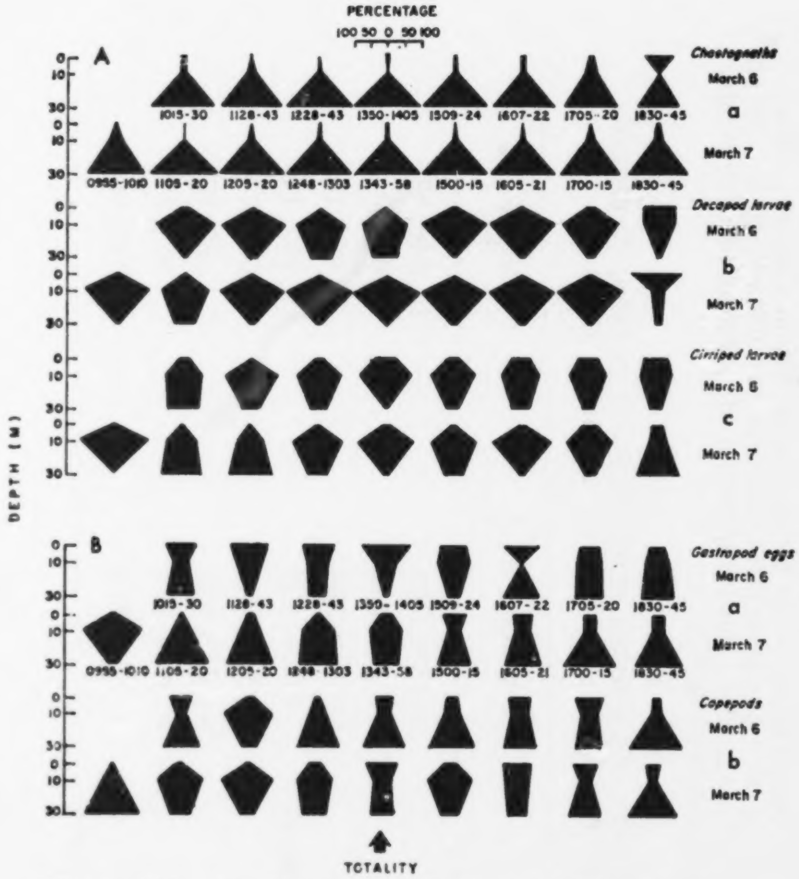


Figure 24. Vertical Distribution of Other Zooplankton Groups. A: percentage occurrence of chaetognaths (b); decapod larva (b), and cirriped larvae (c) at three sampling depths (0, 10, and 30 m) on the pre-eclipse and eclipse days. B: percentage occurrence of gastropod eggs (a) and copepods (b) at three depths (0, 10, and 30 m) on pre-eclipse and elipse days.

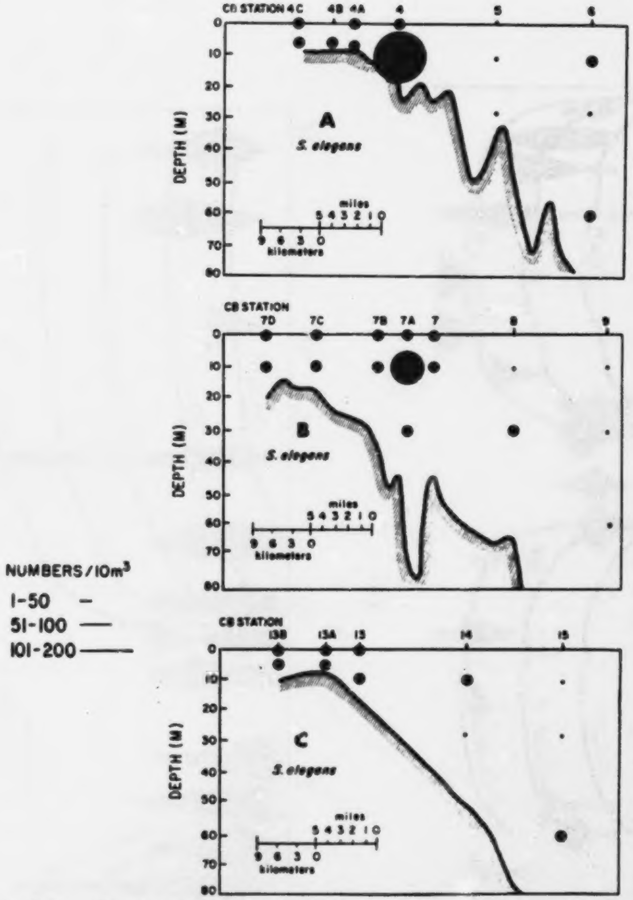


Figure 25. Inshore-Offshore and Vertical Distribution of Sagitta elegans in Three Gulf of Maine Estuaries, Winter 1966 (from Sherman and Schaner, 1968). (A) Piscataqua, (B) Sheepscot, (C) Pleasant. Dots represent positions of the tows; width of the other symbols represent the number of S. elegans per 10 m^3 of water strained.

for the Gulf of Maine area, the ten most important identifiable fish landed are herring, silver hake, cod, ocean perch, haddock, mackerel, pollock, scup, and witch and yellow flounder. Maps of the autumn distribution of 20 common ground fish species in the Gulf of Maine can be found in Fritz (1965) and a brief history of the New England offshore fisheries is given by Jensen (1967). Some characteristics of fisheries important to Maine fisherman, and some of the more abundant fisheries, are presented in tables 10 through 20. Characteristics of the soft shell clam, bloodworm, and sandworm fisheries are not considered because these animals are harvested in shallow estuarine waters.

Graham and Edwards (1961) state that a definite relationship exists between fish catch and benthic biomass and, since the benthic biomass decreases rapidly with depth, one cannot expect any substantial population of fishes on the bottom beyond the continental shelf.

Table 10. Details on the Lobster Fishery

Lobster	*Homarus americanus*	
Characteristics		Data Source*
Landings (lbs)	24,766,000 (rank 6th in U.S.)	1
Economic importance ($)	20,793,000	
Geographical range	abundant: Maine to Nova Scotia; small numbers: Labrador to Middle Atlantic	2
Habitat preferences		
Water depth	inshore: 1 to 30 fathoms offshore: 200 to 500 m, bottom	3 4
Temperature	47 to 49°F	2
Type of bottom	inshore: continental shelf, rocky under seaweed	
Food sources		
Adults	nocturnal feeders; molluscs (living and dead), other invertebrates, plants	2
Growth	slow growing, long lived; min. size (3-3/16 in. carapace) in 4 yr	
Mobility migration		
Vertical	larva pelagic; no extensive migration	5
Horizontal	offshore - fall, inshore - spring	
Spawning	a. larval period: about 2 wk at 68-70°F; about 2 mo at low temperatures b. female (3 1/4 - 5 in. carapace) 6,000-40,000 ova; smallest observed with eggs 8.0 cm c. mate in warm months; eggs hatch following year, 10-11 mo later. c. females moult every 2 yr in May or Sept; after moulting, inpregnation occurs	2,4,6
Natural mortality	about 83% for recruits	7

* 1. Lyles, 1969 2. Dow, 1964. 3. Document No. 51, 1945
4. Skud and Perkins, 1969 5. Commercial Fish. Review, 1964
7. Skerman and Lewis, 1967 7. Lewis, 1970

Table 11. Details on the Shrimp Fishery

Northern shrimp *Pandalus borealis*

Characteristics		Data Source*
Maine landings (lb)	24,335,340	
Economic importance ($)	3,044,948	1
Geographical range	Cape Cod to Nova Scotia	2
Habitat preferences		
Water depth	bottom, 10-300 m	2
Temperature	-2^{o}C to 11.5^{o}C	2
Salinity	30-35 $^{o}/oo$	2
Type of bottom	fine-grained sediment (mud), high in organic carbon (70.5%)	2
Other	fished at less than 60 m depth in winter and spring	2
Food sources		
Adults	omnivorous: plant detritus, worms, crustaceans	3
Growth	7.9 cm (mean) at 14 mo	2
Mobility-migration		
Vertical	diurnal migration, males especially	2
Horizontal	females inshore in fall-winter	2
Behavioral characteristics	distribution independent of temperature and salinity	2
Spawning		
Area	protandic hermaphrodites spawn offshore	
Time of year	eggs laid Aug-Nov, hatch Mar-Apr	2
Larval development time	1 mo approximately	3

*1. Maine Landings, 1969
2. Haynes and Wigley, 1969
3. Anderson, 1966

Table 12. Details on the Sea Herring Fishery

Sea herring (sardine) *Clupea harengus*

Characteristics		Data Source*
Maine landings (lb)	54,213,635	1
Economic importance ($)	967,657	1
Geographical range	New Jersey to Labrador	2,3
Habitat preferences		
Water depth	estuarine inshore spring to fall	3,4,5
Salinity	adults >3 °/oo; below 10°C juveniles prefer >29 °/oo	2
Food sources		
Fry	larval gastropods and crustaceans, diatoms, peridinians	2
Adults	copepods, amphipods, pelagic shrimp, decapod crustaceans	2
Growth	first year: 3 1/2 - 5 in.	2,3
Mobility migration		
Vertical	often school at surface	2
Horizontal	inshore-offshore, fry drift with currents	2
Behavioral characteristics		
Schooling	travel in schools	2
Temperature	active at temperature >40°F	2
Light	attracted to artificial light	7
Other	swimming speed: normal 6-8 m/min, max (60-219 mm) 2.3-4.4 ft/sec; endurance 1-115 min	2,8
Spawning		
Area	Georges Banks and Nova Scotian coast (see figure 26) 5-25 m offshore, hard bottom (gravel), 2-30 fathoms	2
Time of year	autumn - water 46-52°F	2
Position of eggs/larval in water column	demersal, attached to objects; hatch in 10-15 days (eggs warmed to 68°F do not hatch)	2
Larval development time	9 mo	9
Bibliography		10

*1. Maine Landings, 1969 2. Bigelow and Schroeder, 1953 3. Document-No. 51, 1945 4. Graham and Boyar, 1965 5. Scattergood and Lozier, 1964 6. Stickney, 1968 7. Stickney, 1969 8. Boyar, 1961 9. Skud, 1966 10. Scattergood, 1957

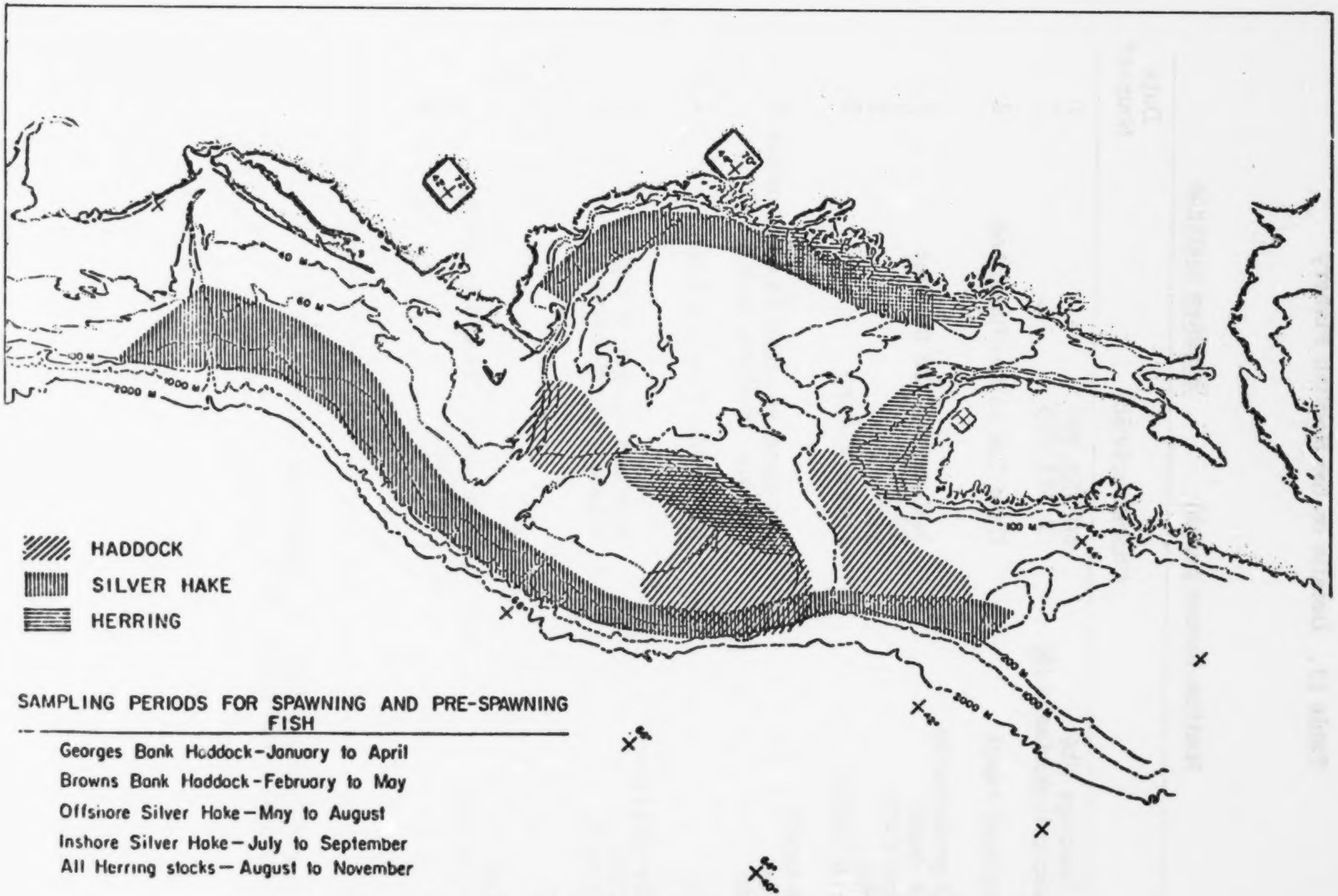

HADDOCK
SILVER HAKE
HERRING
SAMPLING PERIODS FOR SPAWNING AND PRE-SPAWNING FISH
Georges Bank Haddock-January to April
Browns Bank Haddock-February to May
Offshore Silver Hake-May to August
Inshore Silver Hake-July to September
All Herring stocks-August to November
100 M
1000 M
2000 M
60 M
40 M

Figure 26. Spawning Areas of Three Important Fisheries (from Edwards, BCF, Woods Hole, Mass.)

Table 13. Details on the Redfish Fishery

Redfish (ocean perch) *Sebastes marinus*

	Characteristics	Data Source*
Maine landings (lb)	50,752,394	1
Economic importance ($)	2,151,758	1
Geographical range	Cape Cod to Newfoundland	2
Habitat preferences		
Water depth	bottom, 50-125 fathoms	2
Temperature	33-50°F	3
Salinity	32 °/oo	3
Type of bottom	rocky or hard	3
Food sources		
Larvae	crustaceans, mysids, euphausiids	3
Adults	shrimp, mollusc, small fish	
Growth	first year: 1 to 2-1/2 in.	2, 3
Mobility-migration		
Vertical	rise and scatter at night	2
Horizontal	considered extensive	2
Spawning		
Time of year	June-Sept., bear live young; pelagic	2 2

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*1. Maine Landings, 1969 2. Document No. 51, 1945
3. Bigelow and Schroeder, 1953

Table 14. Details on the Silver Hake Fishery

Silver hake (whiting) Merluccius bilinearis

Characteristics		Data Source*
Maine landings (lb)	17,889,677	1
Economic importance ($)	801,872	1
Geographical range	North Carolina to Newfoundland	2
Habitat preferences		
Water depth	bottom, 0-300 ft; wanderers	2
Temperature	40-60°F	3
Type of bottom	no preference	
Food sources		
Adults	shrimp, small fish (herring, mackerel, menhaden, alewife)	3
Growth	first year: 6-1/2 in.	3
Mobility-migration		
Vertical	occupy all depths at times	2
Horizontal	shoreward in spring, offshore in winter	2
Behavioral characteristics	great numbers often swim together in early autumn; strong swimmers	2,3
Spawning		
Area	Cape Cod to Bay of Fundy, inshore and offshore (see figure 26)	2
Time of year	summer; water 45-55°F	2,3
Position of eggs/larvae in water column	eggs pelagic; larvae pelagic-migrate to bottom when about 1-1/2 in. long	2,4

*1. Maine Landings, 1969
2. Fritz, 1962
3. Bigelow and Schroeder, 1953
4. Document No. 51, 1945

Table 15. Details on the Haddock Fishery

Haddock ***Melanogrammus aeglefinus***

Characteristics		Data Source*
Maine landings (lb)	959,466	1
Economic importance ($)	137,041	1
Geographical range	Grand Banks to Cape Cod	2
Habitat preferences		
Water depth	bottom, 30-60 fathoms	3
Temperature	32-52^{o}F	2
Salinity	> 32 $^{o}/oo$	2
Type of bottom	broken ground, gravel, hard sand or clay away from rocks and kelp	2
Food sources		
Fry	zooplankton (copepods)	2,4
Adults	indescriminate feeders: worms, crabs crabs, shrimp, clams, gastropods, starfish, sea urchins, sand dollars, sea cucumbers	2,4
Growth	first year: 6-7-1/2 in.	2,4
Mobility-migration		
Vertical	seldom found near surface	2
Horizontal	not extensive; localized seasonal movement between deep and shoal water	2
Behavioral characteristics		
Schooling	Feb-May	3,4
Spawning		
Area	Georges Bank (see figure 26)	3
Time of year	spring	3
Position of eggs/larvae in water column	pelagic	4
Larval development time	4-5 mo, then bottom existence is begun	4

*1. Maine Landings, 1969
2. Bigelow and Schroder, 1953
3. Document No. 51, 1945
4. Jensen, 1960

Table 16. Details on the Atlantic Mackerel Fishery

Atlantic mackerel Scomber scombrus

Characteristics		Data Source*
Maine landings (lb)	248,598	1
Economic importance ($)	11,658	
Geographical range	Cape Hatteras to Gulf of St. Lawrence	2
Habitat preferences	pelagic: 0-100 fathoms; Gulf of Maine in summer	3
Food sources		
Fry	small copepods	3
Adults	crustacea, squid, sand lance, worms	3
Growth	first year: 8-1/2 in.	4
Mobility migration		
Vertical	all depths	3
Horizontal	extensive migration north in summer and south in fall; offshore in winter	3
Behavioral characteristics	good swimmers; dense schools at all times	3
Spawning		
Area	Chesapeake Bay to Cape Cod favored	2
Time of year	Apr-June, water 46°F	2,3
Position of eggs/larvae in water column	eggs pelagic within 10 m of surface	3
Larval development time	2 in. within 1-2 mo.	3

*1. Maine Landings, 1969
2. Document No. 51, 1945
3. Bigelow and Schroeder, 1953
4. Hoy and Clark, 1967

Table 17. Details on the Cod Fishery

Cod *Gadus morhua*

Characteristics		Data Source*
Maine landings (lb)	4,616,694	1
Economic importance ($)	237,848	1
Geographical range	New Jersey to Labrador	2
Habitat preferences		
Water depth	bottom, 1-250 fathoms	2
Temperature	32-55°F	2
Type of bottom	gravel-sand	2
Food sources		
Fry	small crustaceans	
Adults	molluscs, clams, cockles, mussels crabs, shrimp, tunicates, squid, small fish	2
Growth	first year; 7-1/2 in.	3
Mobility migration		
Vertical	found off bottom occasionally	2
Horizontal	some seasonal movement SW to New York and New Jersey in winter; large majority nonmigratory	2
Behavioral characteristics	often rise to mid depths while schooling	2
Spawning	Georges Bank: Feb-Apr Nautucket Shoals: Nov-Feb Massachusetts Bay: Dec-Feb 32-47°F; 32-32.8 °/oo salinity	2
Position of eggs/larvae in water column	eggs pelagic -- hatch in 2-4 wks;	
Larval development time	larvae pelagic 2-3 mo; seek bottom when 1-1/2 to 2 in.	2

*1. Maine Landings, 1969
2. Bigelow and Schroeder, 1953
3. Document No. 51, 1945

Table 18. Details on the Gray Sole Fishery

Gray sole (witch flounder) Glyptocephalus cynoglossus

Characteristics		Data Source*
Maine landings (lb)	446,782	1
Economic importance ($)	35,898	1
Geographical range	Chesapeake Bay to Nova Scotia	2
Habitat preferences		
Water depth	bottom, deep water fish: 15-700 fathoms	2
Temperature	35-48°F	
Type of bottom	fine muddy sand, clay	2
Food sources		
Adults	invertebrates	2
Growth	first year 2-1/2 to 4 in.	2
Mobility-migration		
Horizontal	local movement	2
Spawning		
Area	Gulf of Maine, water 45-55°F	2
Time of year	late spring and summer	2
Position of eggs/larvae in water column	eggs buoyant	2
Larval development time	fry pelagic: 3-6 mo.	2

* 1. Maine Landings, 1969   2. Bigelow and Schroeder, 1953

Table 19. Details on the Pollock Fishery

American pollock *Pollachius virens*

Characteristics		Data Source*
Maine landings (lb)	1,212,238	1
Economic importance ($)	50,209	1
Geographical range	Nova Scotia to New Jersey	2
Habitat preferences		
Water depth	surface to 100 fathoms	2
Temperature	cold water fish: 32-52°F	
Food Source		
Adult	small fish, pelagic crustaceans (shrimp)	2
Growth	first year: 5-7 in.	2
Mobility-migration		
Vertical	distributed at all levels	2
Horizontal	some seasonal migration southward	2
Behavioral characteristics	often in schools, sometimes very large; active, ravenous fish	2
Spawning		
Area	shoal waters, 10-50 fath, off Mass. Bay	2
Time of year	late fall and early winter	2
Position of eggs/larvae in water column	eggs buoyant; hatch 1-2 wk, fry near surface 3 mo.	

*1. Maine Landings, 1969 2. Bigelow and Schroeder, 1953
3. Document No. 51, 1945

Table 20. Details on the Scup Fishery

Scup (porgy) Stenotomus chrysops

Characteristics		Data Source*
Maine landings (lb)	not identified	
Economic importance ($)		
Geographical range	North Carolina to Cape Cod (casual in Gulf of Maine)	1
Habitat preferences		
Water depth	winter 20-70 fathoms, summer 2-20 fathoms	1
Type of bottom	smooth	1
Food sources		
Adults	bottom feeders; small crustaceans, worms, hydroids, squid, fish fry	1
Growth	first year: 4-1/4 in.	1
Mobility-migration		
Horizontal	some seasonal inshore-offshore migration and some north-south	1
Behavioral characteristics		
Schooling	schooling fish	1
Temperature	sensitive to low temperature	1
Spawning		
Area	inshore waters from New Jersey to Long Island	2
Time of year	May-Aug	
Position of eggs/larvae in water column	eggs buoyant, 2-3 day incubation at 50-75°F	1

*1. Bigelow and Schroeder, 1953 2. Document No. 51, 1945

Benthic Organisms

Studies of benthic animals in the Wiscasset region have been conducted by Stickney (1959) and Hanks (1964). Merrill(1967) has described the offshore distribution of the hydroid, Hydractinia echinata, and Wigley (1968) the benthic invertebrates of the New England fishing banks.

Hanks studied two areas in the Sheepscot River estuary having a silt-clay bottom. A summary of the species found and their abundance is given in table 21. This assemblage is termed a Nephtys-Nucula community after its dominant members. It should be noted that hard bottoms and especially rocky bottoms are extremely difficult to sample with conventional samplers. Consequently, it is safe to assume that this community is but a minor part of the species living generally in or on the highly variable bottom in the Wiscassett region. This is shown by the list of common animals and plants recorded by Stickney (1959) in the Wiscassett estuary (table 22).

Wigley (1968) described the benthic invertebrates of the New England fishing banks associated with types of bottom sediments prevalent in the Gulf of Maine; i.e., sandy, silty-sand, gravel, and mud.

Some common species occupying a sandy bottom included: Echinarachnius parma (sand-dollar); Crangon septemspinosis (sand shrimp); Lunatia heros and Nassarius trivitattus (gastropods); Spisula solidissima (surf clam); Astarte castanea (bivalve); Leptocuma sp. (crustacean); Chridotea sp. (isopod); Pagurus acadianus (hermit crab); Ophelia, Goniadella, and Clymenella sp. (polycheate worms); Heterostigma and Molgula sp. (tunicates).

Some of the common inhabitants of silty-sand sediments were: Arctica islandica (ocean quahog); Thyone scabra (sea cucumber); Ampelisca vadorum and A. compressa (amphipods); Dichelopandulus sp. (decapod shrimp); Diastylis sp. (cumacean); Edotea sp. (isopod), Scalibregma, Nepthys, and Harmothoe sp. (polycheates); Cerianthus sp. (sea anemone), Amphioplus and Amphilimna sp. (brittle stars), Colus pygmacus (gastropod); and Venericardia, Nucula, and Crenella sp. (bivalves).

Some species occupying gravel bottoms included: Polymastia, Clionia, and Myxilla sp. (sponges); Balanus crenatus and B. hameri (barnacles); Tubularia, Eudendrium, Sertularia, and Bouganvillia sp. (hydroids); Terebratulina sp.

Table 21. Species in the Nephtys-Nucula Community Found at 10 or More Stations in Ebencook Harbor and Jewett Cove, Maine, Listed in Order of Abundance (from Hanks, 1964)

Rank by Number	Species	Number	Number of Stations	Percentage by Number	Cumulative Percentage	Percentage of Stations	Average Number per m²	Area*	Depth Range in Survey (m)
1	Nucula proxima	2,358	59	18.3	18.3	75.6	399.6	E,J	4-30
2	Cumacea sp. (4+species)	1,973	55	15.3	33.6	70.5	358.7	E,J	4-14
3	Stereobalanus canadensis	768	34	6.0	39.6	43.6	225.8	E,J	3-31
4	Thyasira gouldi	717	46	5.6	45.2	59.0	155.8	E,J	4-31
5	Phoxocephalus holbolli	623	39	4.8	50.0	50.0	159.7	E,J	1-9
6	Volsella modiolus	573	68	4.4	54.4	87.2	84.2	E,J	1-31
7	Corophium sp.	557	22	4.3	58.7	28.2	253.1	E, mostly J	0-8
8	Nucula tenuis	515	46	4.0	62.7	59.0	111.9	E,J	4-31
9	Dulichia sp.	407	39	3.2	65.9	50.0	104.3	E,J	5-14
10	Scoloplos armiger	402	47	3.1	69.0	60.3	85.5	E,J	14-4
11	Aricidea sp.	395	43	3.1	72.1	55.1	91.8	E,J	1-14
12	Nephyts incisa	332	70	2.6	74.7	89.7	47.4	E,J	1-31
13	Orchomenella pinquis	292	28	2.3	79.3	35.9	104.2	E,J	4-14
14	Ampelisca spinipes	291	28	2.3	77.0	35.9	103.9	E,J	1-14
15	Diplocirrus hirsutus	253	19	2.0	81.3	24.4	133.1	E,J	6-13
16	Retusa obtusa	206	48	1.6	82.9	61.5	42.9	E,J	2-31
17	Sternaspis scutata	198	31	1.5	84.4	39.7	63.8	E,J	5-31
18	Hartmania moorei	155	39	1.2	85.6	50.0	39.7	E,J	5-31
19	Ampharete acutifrons	135	42	1.0	86.6	53.8	32.1	E,J	4-31
20	Nemertea sp.	134	49	1.0	87.6	62.8	27.3	E,J	--
21	Casco bigelowi	134	16	1.0	88.6	20.5	83.7	E,J	5-8
22	Nucula delphinodonta	119	11	0.9	89.5	14.1	108.1	E	3-8
23	Pholoe minuta	100	40	0.8	90.3	51.3	25.0	E,J	4-13
24	Cingula aculeus	94	18	0.7	91.0	23.1	52.2	E,J	4-14
25	Crenella decussata	76	24	0.6	91.6	30.8	31.6	E,J	4-31
26	Alucena vincta	75	31	0.6	92.2	39.7	24.1	E,J	4-31
27	Lumbrineris fragilis	64	40	0.6	92.8	51.3	18.5	E,J	4-31
28	Pherusa plumosa	66	28	0.5	93.3	35.9	23.5	E,J	4-13
29	Yoldia sapotilla	66	20	0.5	93.8	25.6	33.0	E,J	8-31
30	Aeginina longicornis	64	20	0.5	94.3	25.6	32.0	E,J	6-14
31	Ninoe nigripes	48	27	0.4	94.7	34.6	17.7	E,J	4-31
32	Ammotrypnae aulogaster	34	12	0.3	95.0	15.4	28.3	E,J	1-31
33	Aricidea quadrilobata	33	14	0.3	95.3	17.9	23.5	E,J	1-14
34	Cerastoderma pinnulatum	32	17	0.2	95.5	21.8	18.8	E,J	3-31
35	Tellina agilis	32	19	0.2	95.7	24.4	16.8	E,J	1-31
36	Lora scalaris	31	20	0.2	95.9	25.6	15.5	E,J	4-14
37	Leptocheirus pinquis	27	15	0.2	96.1	19.2	18.0	J	4-13
38	Trichobranchus roseus	27	14	0.2	96.3	17.9	19.2	E,J	8-31
39	Rhodine loveni	25	16	0.2	96.5	20.5	15.6	E,J	4-13
40	Yoldia limatula	25	15	0.2	96.7	19.2	16.6	E,J	5-10
41	Nassarius trivittatus	20	16	0.2	96.9	20.5	12.5	E,J	5-31
42	Phyllodoce groenlandica	18	12	0.1	97.0	15.4	15.0	J	4-13
43	Terebellides stroemi	17	14	0.1	97.1	17.9	12.1	E,J	5-14
44	Pitar morrhuana	16	11	0.1	97.2	14.1	14.5	E,J	5-31
45	Astarte undata	15	11	0.1	97.3	14.1	13.6	E,J	4-31
46	Priapulus caudatus	15	11	0.1	97.4	14.1	13.6	E,J	6-14
47	Edotea triloba	14	11	0.1	97.5	14.1	12.7	mostly J	1-13
48	Sarsiella americana	11	10	0.1	97.6	12.8	11.0	mostly J	1-13
49	Miscellaneous	--	--	2.4	100.0	--	--	--	--

*E = Ebenecook Harbor, J = Jewett Cove

Table 22. Common Aquatic Animals and Plants Collected or Recorded from Sheepscot Estuary, Arranged According to Habitat (adapted from Stickney, 1959)

Common Aquatic Animals*

I. High salinity, infauna of subtidal sediments	
Coelenterates	
Cereantheopsis americana Verrill	sea anemone
Edwardsia elegans Verrill	sea anemone
Acaulis primarius Stimpson	
Polychaete worms:	
Pholoe minuta Fabricius	
Phyllodoce groenlandica Oersted	
Nereis virens Sars	
Nephtys incisa Malmgren	
Nephtys caeca Fabricius	
Lumbrinereis tenuis Verrill	
Ninoe nigripes Verrill	
Aricidea spp.	
Diplocirrus hirsutus Hansen	
Flabelligera affinis Sars	
Pherusa plumosa Muller	
Scalibregma inflatum Rathke	
Ammotrypane aulogaster Rathke	
Maldane sarsi Malmgren	

---

*This list contains but a small fraction of the aquatic organisms in the estuary. The most interesting, conspicuous, or abundant species of fish and invertebrates are listed according to the habitat in which they are most likely to be found. It does not follow, however, that every situation where these various conditions prevail will be inhabited by every species listed for that habitat, nor that many species so listed will not be found elsewhere.

Most of these animals have no common names, but where such a name is in general usage it is included in the righthand column of the table as an aid to those not familiar with the Latin names. As a further aid, the species are arranged in groups of more or less related members.

Table 22 (Cont'd)

Praxillela spp.	
Rhodine loveni Malmgren	
Ampharete acutifrons Grube	
Sternaspis scutata Ranzani	
Hartmania moorei Pettibone	
Molluscs:	
Yoldia limatula Say	
Yoldia sapotilla Gould	
Nucula spp.	
Thyasira gouldii Phillipi	
Cerastoderma pinnatulum Conrad	cockle
Clinocardium ciliatum Fabricius	cockle
Crenella decussata Montagu	
Thracia myopsis Muller	
Tellina agilis Stimpson	
Astarte undata Gould	
Crustaceans:	
Phoxocephalus holbolli Kroyer	
Orchomenella pinguis Boeck	
Leptocheirus pinguis Stimpson	
Corophium spp.	
Casco bigelowi Blake	
Ampelisca spinipes Boeck	
Dulichia sp.	
Diastylis quadrispinosa Sars	
Eudorella sp.	
Echinoderms:	
Caudina arenata Gould	sea cucumber
Ophiura robusta Ayres	brittle star

Table 22 (Cont'd)

II. High salinity, subtidal epifauna, solid substrate	
Sponges:	
Halichondria sp.	
Chalina oculata Pallas	deadman's fingers
Coelenterates:	
Metridium dianthus Ellis	sea anemone
Urticina crassicornis Muller	sea anemone
Obelia spp.	
Sertularia spp.	
Polychaete worms:	
Harmathoe imbricata Linnaeus	scailed worm
Lepidonotus squamatus Linnaeus	scailed worm
Spirorbis borealis Daudin	
Molluscs:	
Hiatella arctica Linnaeus	
Anomia simplex Orbigny	jingle shell
Anomia aculeata Gmelin	
Ischnochiton ruber Linnaeus	
Aeolidia papillosa Linnaeus	
Odostomia bisuturalis Say	
Crustaceans:	
Balanus crenatus Bruguiere	barnacle
Idothea baltica Pallas	
Idothea phosphorea Harger	
Aeginella longicornis Kroyer	
Gammarus marinus Leach	beach flea
Gammarus annulatus Smith	
Echinoderms:	
Asterias vulgaris Verrill	common starfish
Asterias forbesi Desor	purple starfish
Henricia sanguinolenta O. F. Muller	blood starfish

Table 22 (Cont'd)

	Ophiopholis *aculeata* Linnaeus	brittle star
	Gorganocephalus *arcticus* Leach	basket star
	Cucumaria *frondosa* Gunnerus	sea cucumber
	Strongylocentrotus *droehbachiensis* O. F. Muller	sea urchin
	Protochordates:	
	Boltenia *echinata* Linnaeus	sea squirt
	Amaroucium sp.	
	Didemnum *albidum* Verrill	
	Dendrodoa *carnea* Agassiz	
III.	High salinity, subtidal, soft bottom epifauna	
	Molluscs:	
	Placopecten *magellanicus* Gmelin	sea scallop
	Retusa *obtusa* Montagu	
	Lacuna *vincta* Turton	
	Nassarius *trivittatus* Say	mud snail
	Cingula *aculeus* Gould	
	Cylichna *alba* Brown	
	Colus sp.	distaff shell
	Crustaceans:	
	Pandalus *borealis* Kroyer	shrimp
	Crago *septemspinosus* Say	mud shrimp
	Echinoderms:	
	Echinarachnius *parma* Lamarck	sand dollar
IV.	High salinity, miscellaneous bottom types, wanderers	
	Crustaceans:	
	Homarus *americanus* Milne-Edwards	lobster
	Cancer *borealis* Stimpson	Jonah crab
	Cancer *irroratus* Say	rock crab
	Carcinides *moenas* Linnaeus	green crab
	Hyas *araneus* Linnaeus	toad crab
	Pagurus *bernhardus* Linnaeus	hermit crab

Table 22 (Cont'd)

V. Nekton, anadromous and catadromous, migratory	
Pomolobus pseudoharengus Wilson	alewife
Pomolobus aestivalis Mitchill	glut herring
Alosa sapidissima Wilson	American shad
Salmo salar salar Linnaeus	Atlantic salmon
Osmerus mordax Mitchill	American smelt
Roccus saxatilis Walbaum	striped bass
VI. Plankton, high salinity coastal waters	
Coelenterates:	
Cyanea arctica Peron and Leseuer	red jellyfish
Aurelia aurita Linnaeus	white jellyfish
Ctenophores:	
Pleurobrachia pileus Fabricius	sea walnut
Chaetognaths:	
Sagitta spp.	arrow worms
Copepods:	
Calanus finmarchicus Gunner	
Pseudocalanus minutus Kroyer	
Centropages typicus Kroyer	
Centropages hamatus Lilljeborg	
Temora longicornis Muller	
Eurytemora herdmani Thompson and Scott	
Acartia longiremis Lilljeborg	
Tortanus discaudatus Thompson and Scott	
Microsetella norvegica Boeck	
Oithona similis Claus	
Cladocerans:	
Evadne nordmanni Loven	
Podon leukarti Sars	
Tintinnids:	
Tintinnopsis sp.	

Table 22 (Cont'd)

Common Aquatic Plants*	
I. High salinity coastal waters	
Algae:	
Laminaria longicruoris De la Pylaie	kelp
Laminaria digitata Linnaeus	kelp
Fucus vesiculosus Linnaeus	rockweed
Fucus spiralis Linnaeus	rockweed
Fucus evanescens C. Agardh	rockweed
Ascophyllum nodosum Linnaeus	rockweed
Chorda filum Linnaeus	
Desmarestia aculeata Linnaeus	
Chordaria flagelliformis Muller	
Chondrus crispus Linnaeus	irish moss
Polysiphonia lanosa Linnaeus	
Polysiphonia flexicaulis Harvey	
Corallina officinalis Linnaeus	
Ulva latuca Linnaeus	sea lettuce
Enteromorpha compressa Linnaeus	
Seed Plants:	
Spartina alterniflora var. *glabra* Fernald	marsh grass
Spartina patens Ait.	marsh grass
Zostera marina Linnaeus	eel grass

*None of these plants should occur at depths of 250 ft.

(lampshells); *Gersemia* and *Paragorgia* sp. (soft corals); *Boltenia*, *Ascidia*, and *Amaroucium* sp. (tunicates); *Modiolus*, *Placopecton*, *Anomia*, and *Musculus* (bivalves); *Serpula*, *Chone*, and *Spirobis* (polychaetes); *Solaster* and *Crossaster* (starfishes); *Neptunea* (gastropod); *Hyas* (toadcrab); *Doris* and *Dendronotus* sp. (nudibranchs); and *Ophiopholis* and *Ophiacantha* sp. (brittle-stars).

Finally, species found associated with muddy bottom were: *Briaster fragilis* (heart urchin); *Ophiura sarsi*, *O. robusta*, and *Amphiura otteri* (brittle stars); *Cteniodiscus crispatus* (mud star); *Modiolaria discors* (bivalve); *Scaphander* sp. (gastropod); *Cadulus* and *Dentalium* sp. (tusk shells); *Haploops tubicola* (amphipod); *Munnopsis typica* (isopod); *Calocaris*, *Geryon*, and *Pandalus* sp. (decapods); *Polycarpa fibrosa* (ascidian); and *Sternaspis*, *Amphritrite*, *Onuphis*, and *Learnira* sp. (polycheates).

Wigley and Emery (1968) have also reported on the distribution patterns of commercially important mollusks based on submarine photographs. They present distribution maps and report that the sea scallop (*Placopecten magellanicus*), surf clam (*Spisula solidissima*), and ocean quahog (*Arctica islandica*) are restricted to the continental shelf.

Fouling

A list of fouling organisms found in Penobscot Bay, Maine, and Placentia Sound, Newfoundland, is presented in table 23 (DePalma, 1969). According to DePalma, the fouling communities can be classified as boreal. Very little fouling occurs during the winter months.

At depths greater than 50 ft, barnacles and other calcareous cementing animals such as tubeworms dominate the fouling community. The data in table 24 show that the mass of organisms that attach to surfaces decreases with increasing depths. Periods of settlement of five important fouling organisms are given in figure 27. The data show that the greatest settlement occurs during the summer months.

The intertidal fouling community at Penobscott Bay, Maine, has been studied by Rucker (1964). Rucker lists some subtidal species that may occur at the depth we are considering.

Table 23. Local Abundance of Marine Fouling Organisms, 1960 to 1968 (from DePalma, 1969)

Species	Searsport 25'	Isesboro 20'	Port Clyde 45'	Brewster 45'	Mark Island 50'	Mark Island 100'	Mark Island 150'	Mark Island 200'	Placentia Sound 50'	Placentia Sound 95'
Algae										
Ulva lactuca	XX		XX	XX	XX				XX	
Enteromorpha sp.	XX	X	XX	XX	XX				XX	
Laminaria saccharina			X	XXX	XX					
L. digitata				X					XX	
Chordaria fragelliformis				X						
Desmarestia viridis				XX						
Porphyra umbilicus				X						
Ceramium rubrum	X			XX	X					
Polysiphonia sp.				X	XX					
Lithothamnium sp.			X							
Agardhiella sp.				X						
Porifera										
Leucosolenia sp.				X						
Sycon protectum									X	
Coelenterata										
Obelia sp.	X	XX	X	XX	XXX	XX			XX	XX
Tubularia crocea	XXX	XXX		XX	X	XX	XX	XX	XX	
Sertularia sp.						XX	XX	XX		
Metricium dianthus	X			X		X				
Bryozoa										
Hippothoa hyalina		X	X							
Cribrilina annulata		X	X							
Tegella unicornis	X	X	X	X					XX	XX
Schizomevella auriculata				XX						
Ramphostomella radiatula									XX	XX
R. costata										XX
Dendrobeania murrayana										X
Cryptosula pallasiana			X	X						
Smittina trispinosa			X						XX	
Gemellaria loricata									X	
Electra pilosa		X	X		XX	XX	XX	XX	XX	XX
Hippodiplosa sp.									XX	
Paramittina sp.									X	
Cylindroporella tubulosa									X	
Tubulipora flabellaris		X	X			XX	XX	XX	XX	XX
Crisia eburnea							XX	XX	XX	
C. cribraria									XX	
Bugula turrita						XX	X		XX	
Disporella fimbriata		X	X				XX	XX	XX	
Lichenpora verrucaria	XX	XX	XX	XX	XX					XX
Manipea tenella				XX	XX				XX	
Annelida										
Spirorbis borealis	XX	XX	XX	XX		XX		XX	XX	XX
S. granulatis		X	XX	X		XX			XX	XX
S. spirillum		X	XX				XX	XX	XX	XX
Chitinopoma greenlandica									XX	
Hydroides sp.	X	X	X	X		X				
Arthropoda										
Balanus crenatus	XX	XXX	XX	XXX	XX	XX			XX	XX
B. balanoides		X	X	X					X	X
B. balanus				X						
B. hameri							XX	XX		
Isopoda										
Lignoria lignorum	T	T	C	T					T	T
Mollusca										
Mytilus edulis	XXX	XX	X	XX	XX				XX	
Histella arctica		XX	XX	XX		XX	XX	XX	XX	XX
Anomia simplex	XX	XXX	XX	XXX		XX	XX	XX	XX	XX
A. aculeata		X	X	XX		X			X	
Acmaea testudinalis		X	X	X						
Pectin vitreus				X		X	X	X	X	
Modiolus modiolus				X						
Teredo navalis	T	T	T	T						
Xylophaga atlantica							T	T	T	T
Chordata										
Molgula sp.				X					X	
Botryllus sp.				X	XX					

XXX = Occurs commonly on series I panels; sometimes covers more than 40% of panel surface.
XX = Occurs commonly on series I panels; never covers more than 40% of panel surface.
X = Occurs occasionally on series I panels or never exceeds 1% coverage of panel surface.
T = Marine borer; less than 10% of wooden panel destroyed after 12 months exposure.
C = Marine borer; 10 to 25% of wood destroyed after 12 months exposure.

Table 24. Rate of Fouling Based on Dry Weight Accumulation per Unit Time (from DePalma, 1969)

Months of Exposure	Dry Weight in gm/m^2 from Pane Is Exposed 1-2 Ft above Bottom in Depths Shown							
	50' Brewster Point	100' Mark Island	150' Mark Island	200' Mark Island	25' Searsport	20' Isleboro	20' Port Clyde	100' Placentia Sound
1	<50							
2	<50							
3	67							
4	<50							
5	67							
6	79							
7	<50							
8	56							
9	90							
10	--							
11	156							
12	247	247	195	112	<50	<50	<50	<50
24	5,400							<50
36	13,387							
48	5,287							

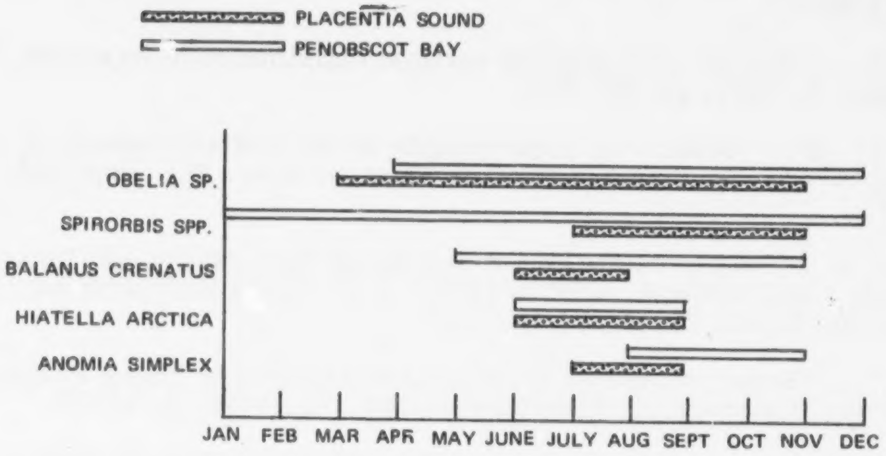

Figure 27. Periods of Settlement for Five Important Fouling Organisms (from DePalma, 1969)

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Section 3
SITE DESCRIPTION FOR THE NEW YORK BIGHT

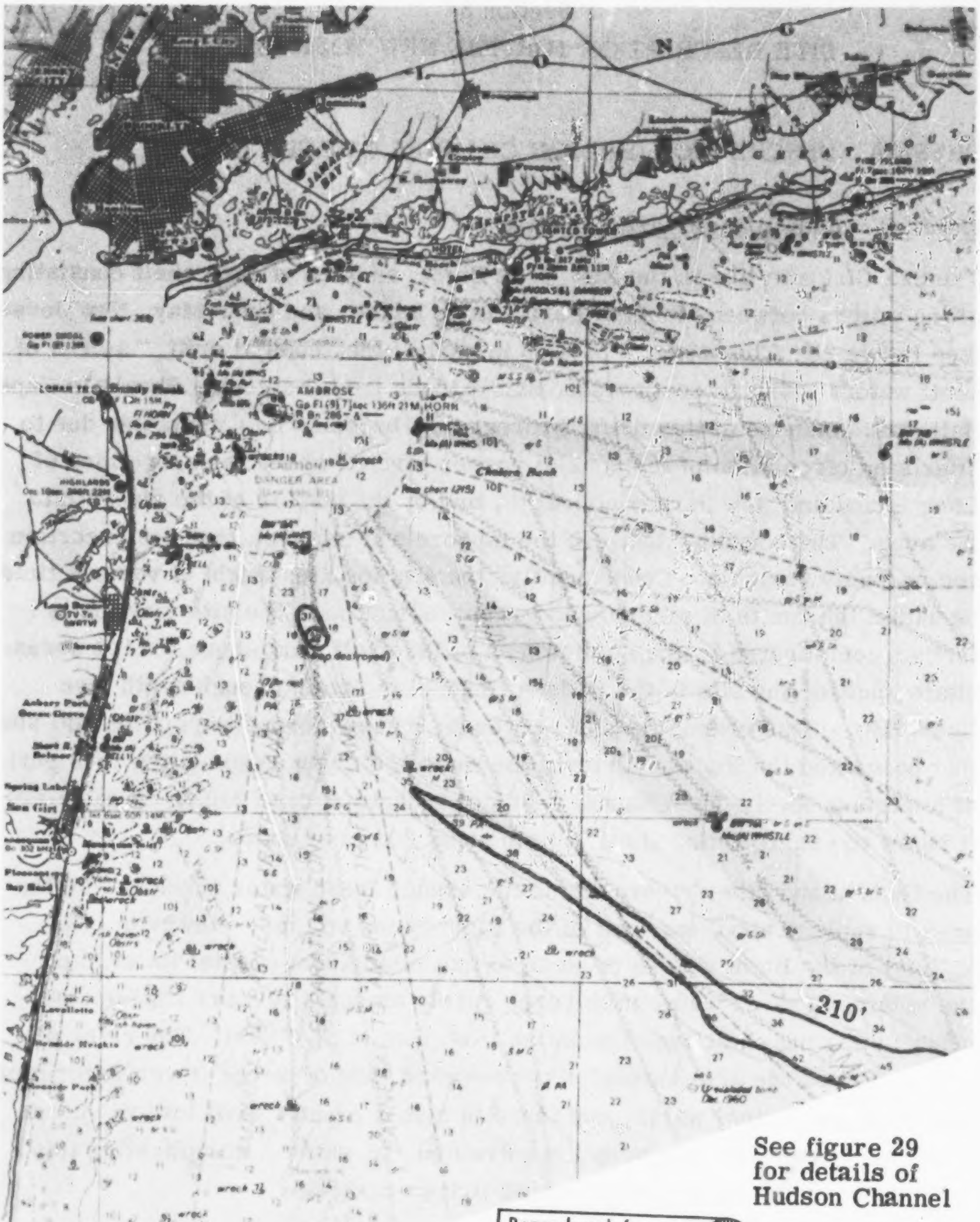
PHYSICAL DESCRIPTION (HUDSON CHANNEL OFF SEA GIRT)

Water Circulation and Characteristics

The Sea Girt site lies in the New York Bight, an area of open shelf consisting of the waters between Montauk Point, Long Island, and Cape May, New Jersey (see figure 28). The offshore portion is part of the "coastal drift," a drift of shelf waters, flowing south-west, that extends from Nantucket Shoals to Cape Hatteras. Inshore of this drift, hydrography becomes more complex due to effects on circulation of the coastal corner formed where the shorelines of Long Island and New Jersey converge, and by the outflow of the rivers into the area. The boundary between the inshore and offshore zones is uncertain and probably variable. Consequently, the site location might at various times be within the limits of either hydrographic situation. The site location is further complicated by the shallowness of the shelf near shore, which necessitates putting the site in the Hudson Channel to obtain enough depth (see figure 29). This channel is a deep trough, cutting across the continental shelf, that connected the Hudson River to the Hudson Canyon at some previous period of lower sea level. The Channel provides a depth of over 240 ft, roughly 120 ft below the surrounding shelf, within about 20 nm of shore.

The Hudson and other rivers discharge enough fresh water annually into the area to replace about one-half of the Bight water volume. However, the salinity of the Bight waters is close to that of adjacent coastal water, and the volume of river water in the area rarely amounts to more than one percent, indicating an active circulation (Ketchum et al, 1951). The river discharge leaves the area through a net seaward flow of mixed (river water plus entrained sea water) water, and there is also a counter drift toward shore along the bottom that replaces the entrained sea water. Complicating this circulation pattern are tidal and wind-driven currents.

The physical structure of the waters of the New York Bight is primarily dependent upon two factors: season and the river discharge. Table 25 tabulates the physical properties by the season, and figure 30 gives the temperature profiles of the water. In winter the water is well mixed and nearly isothermal.


AMBROSE
CAUTION
DANGER AREA
210'

See figure 29
for details of
Hudson Channel

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Figure 28. Soundings (Fathoms) in Part of the New York Bight (from Coast and Geodetic Survey Chart 1108)

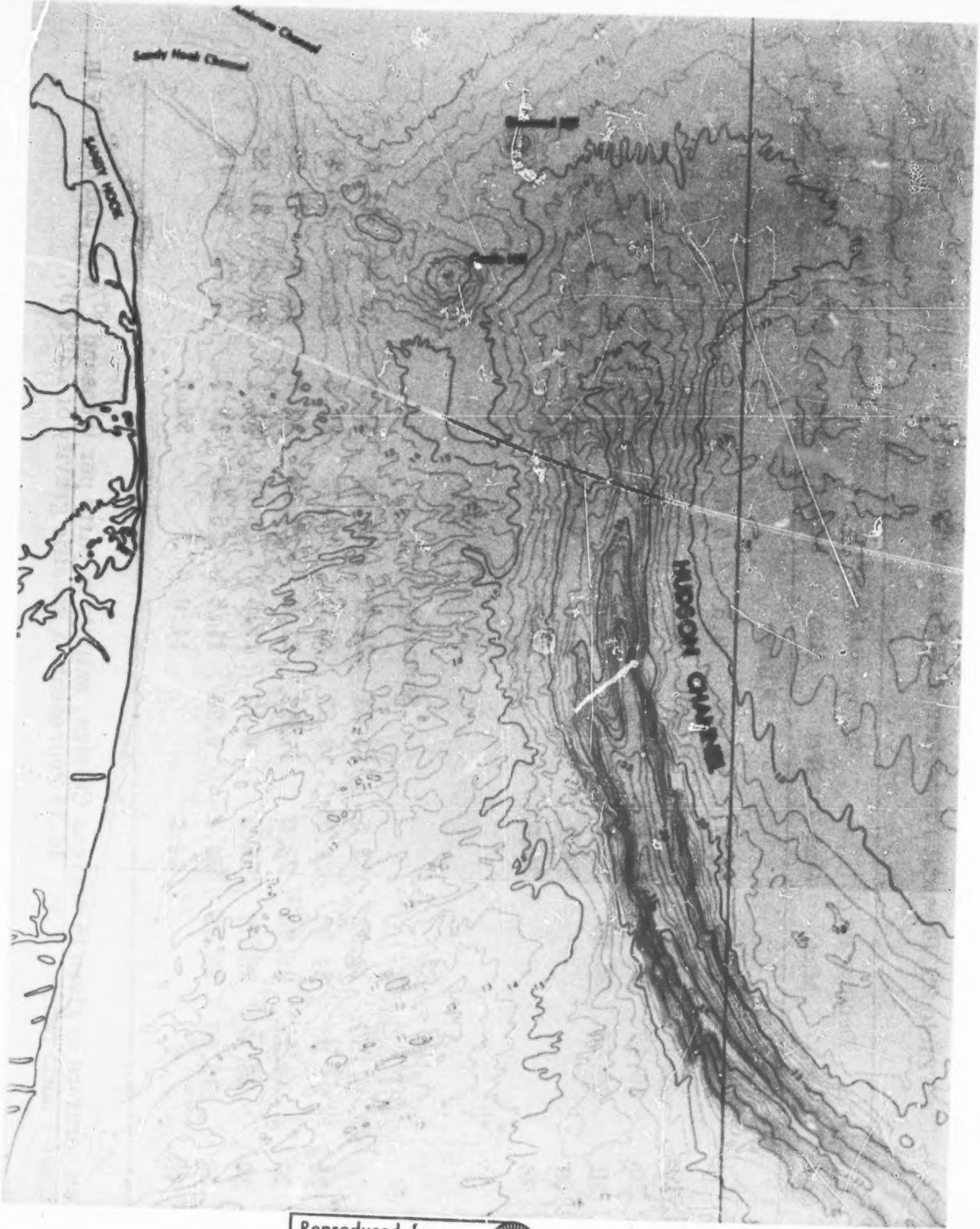
Ambrose Channel
Sandy Hook Channel
SANDY HOOK
HUDSON CHANNEL

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Figure 29. Bathymetric Details (Fathoms) of the Head of the Hudson Channel (from Coast and Geodetic Survey Maps 0807N-54 and 0808N-55)

Table 25. Physical Properties of Water at the New York Bight Site

Depth (m)	Density (ρ_t)			Temperature (^{o}C)			Salinity ($^{o}/oo$)		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
					Winter				
0	25.37	26.09	25.7	7.19	9.5	3.61	32.2	33.07	31.55
10	25.40	26.09	25.7	7.26	9.8	3.57	33.4	33.07	31.59
20	25.47	26.06	25.8	7.38	10.2	3.58	33.6	33.38	31.74
30	25.56	26.06	25.8	7.40	10.5	3.60	33.7	33.58	32.20
50			25.9		10.6	4.00	33.8	34.26	34.26
75			26.0		10.7		33.9		
					Summer				
0	21.37	23.32	21.3	21.53	24.0	16.79	31.3	32.20	11.57
10	22.03	24.05	21.31	19.82	33.0	12.72	31.5	32.56	18.89
20	24.33	25.70	22.0	11.75	21.0	6.28	31.7	32.70	31.44
30	25.21	25.77	24.5	8.12	15.5	5.61	32.1	32.83	31.52
50	25.60	25.78	24.9	6.74	11.5	5.94	32.2	32.72	32.30
75			24.9		11.0		32.2		

*Temperature is given in degrees Celsius, salinity in parts per thousand ($^{o}/oo$), and density in sigma-t units (where, e.g., 24.39 represents a specific gravity of 1.02439).

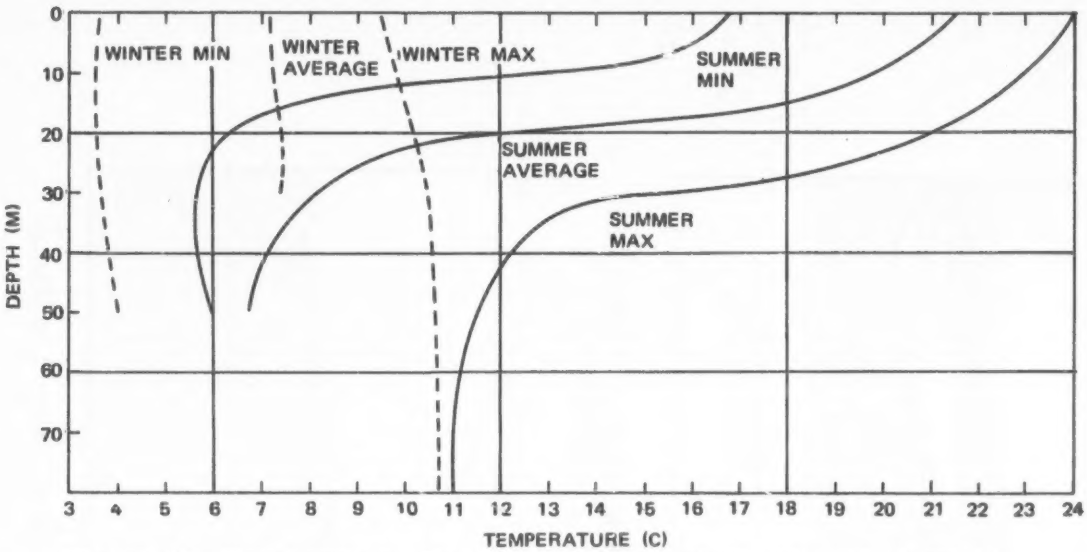


Figure 30. Temperature Profiles of Water at the New York Bight

During the winter, river outflow is reduced and flows southward close to the New Jersey shoreline (Ketchum et al, 1951) inside the site area. In summer a well-stratified condition exists with a gradient of as much as 17°C. During this season, the river discharge spreads across the Bight area more or less evenly (Ketchum, 1951). Note the occurrance of low salinity values during the summer (table 25). Storm conditions will cause mixing and destroy any stratification, but observations suggest that stratification will be reestablished within about 2 days (Ketchum, 1951).

The conditions described apply to the Bight area in general; but in the Hudson Channel site, water conditions may vary somewhat. Figures 31 and 32 show typical temperature cross-sections across the channel. In summer the observed "hump" of isotherms over the channel commonly appears, channel water being slightly colder than the adjacent waters. In winter the reverse occurs, channel water being slightly warmer. Study of physical properties profiles in Ketchum indicates that water in the Hudson Channel more closely resembles water from further offshore than it does the adjacent shelf water. From this it is suggested that there may be up-channel drift of offshore water.

The structure of the current at this site is discussed here in a manner leading from a general picture to the specific conditions at the site. The intent is to supply necessary background information and to explain the rationale behind certain estimates that must be made where raw data is lacking.

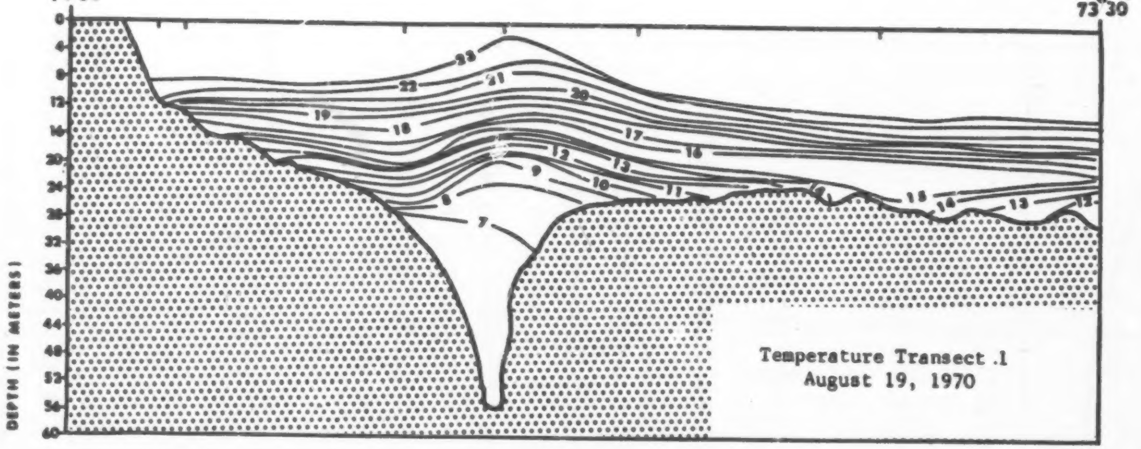


Figure 31. Temperature Profile Across the Hudson Channel in Summer (from Sandy Hook Marine Laboratory, unpublished)

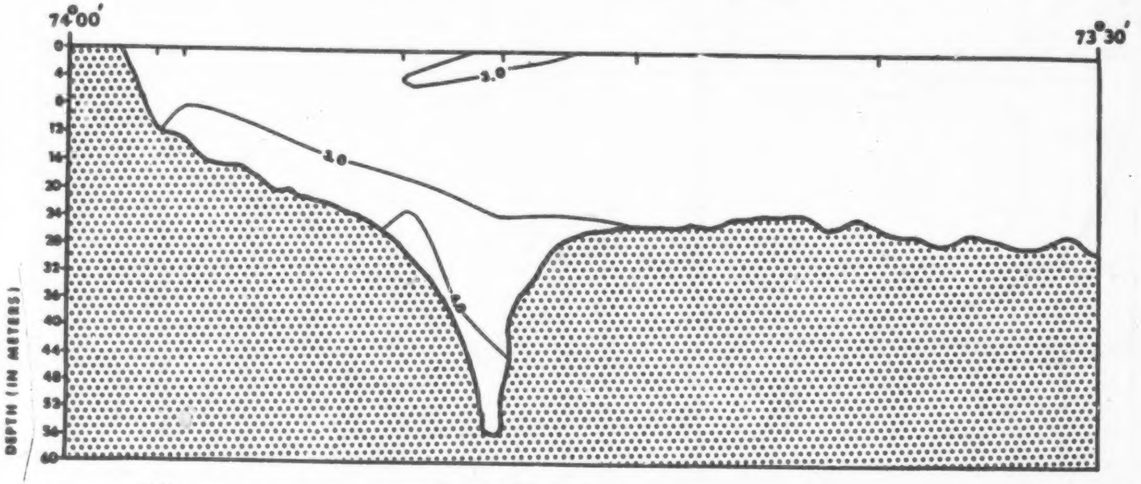


Figure 32. Temperature Profile Across the Hudson Channel in Winter (from Sand Hook Marine Laboratory, unpublished)

The characteristics of the nearshore, or coastal, current result from the superposition of various effects; e.g., bottom friction, wind, runoff, density, coriolis force, etc. The accurate prediction of coastal flow, then, depends on a knowledge of the components. It follows also that, if a component factor is subjected to an anomaly, the resultant coastal flow may differ from that expected. Some of these component factors, as applied to the northeast shelf region, are described in the following paragraphs:

1. Lateral current shear on the landward side of the Gulf Stream tends to form a circulation pattern with southwesterly-directed trajectories nearshore. This phenomenon is somewhat analogous to a turbulent boundary layer.

2. The southbound Labrador Current, especially pronounced in the northern section of this region, tends to hug the coastline because of the coriolis force.

3. Fresh water runoff from rivers, sounds, and estuaries, piling up along the east coast in spring and early summer, tends to produce a seaward pressure gradient and a resultant flow to the south due to coriolis force. Bumpus (1969) states: "It is generally the case that coastal currents flow nearly parallel to the coast with land on the right in the northern hemisphere, where there is adequate fresh water discharge from the adjacent watersheds."

4. In winter, prevailing winds from the northwest quadrant exert a stress on the sea surface over the shelf that tends to cause a mass transport southward. In summer, prevailing winds from the southwest tend to transport water offshore, or to the east. The frequency of wind direction, by velocity, is given in table 26.

5. The vertical structure of currents, in a region on the shelf that is affected by river flow, often exhibits a counter flow in the bottom layers. This is due to entrainment or mixing of deep salty water into the upper, out-flowing layer, and the replacement of this salty water. Thus, although the surface layer moves in one direction, the bottom layer moves in the opposite direction to maintain the steady state.

Table 26. Frequency of Wind Direction by Speed -- Annual Percentage (from U.S.N. Weather Service Command, 1970)

Wind Direction	Wind Velocity (knots) 0-6	7-16	17-27	28-40	41+	Number of Observations	Percentage of Frequency	Mean Speed
N	2.3	4.1	2.0	0.5	*	1450	8.9	12.8
NE	1.8	4.1	2.2	0.7	0.1	1446	8.9	14.3
E	2.4	4.2	1.3	0.2	*	1342	8.3	11.2
SE	2.9	4.2	1.0	0.1	*	1333	8.2	9.9
S	4.8	9.7	2.7	0.3	0.0	2850	17.5	11.0
SW	3.9	8.8	2.8	0.4	*	2581	15.9	11.7
W	2.9	7.9	4.5	1.3	0.1	2717	16.7	14.5
NW	2.0	5.8	3.7	0.9	0.1	2015	12.4	14.7
Variable	*	0.0	0.0	0.0	0.0	5	*	2.4
Calm	3.2					514	3.2	0.0
Number of Observations	4243	7931	3295	712	72	16253		12.2
Percentage	26.1	48.8	20.3	4.4	0.4	100.0	100.0	(mean total)

*frequencies between 0.0% and 0.05%

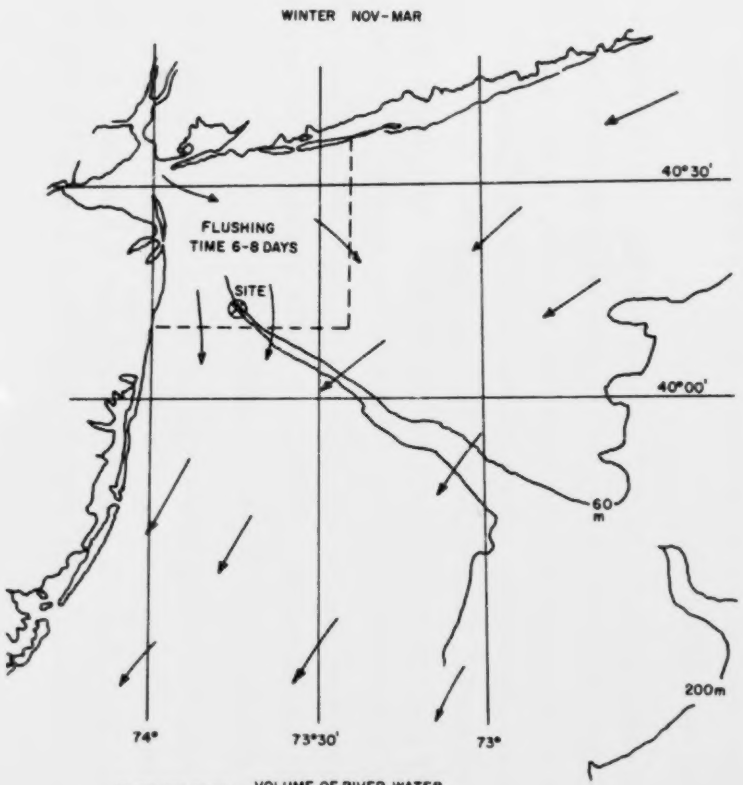
6. Tidal currents in restricted areas, such as nearshore or in channels, exhibit rectilinear flow, flowing in one direction for half the tidal period and in the opposite direction for the remainder of the period. In offshore areas, tidal currents are of a rotary nature in the form of an ellipse with the major axis in the flood-ebb direction. Although there is not net transport due to tidal currents, there is a contribution to mixing from them.

The resulting current structure, or that which is measured, is the superposition of these component currents. Some of the components are aperiodic while others are periodic, with periods ranging from the semiannual to the annual.

Data from Bureau of Commercial Fisheries, Wood's Hole Oceanographic Institute, and the U.S. Navy indicate that average surface drift in the Sea Girt area is 0.3 knots, or about 6 nm per day, and the expected range of surface drift speed is from 2 to 11 nm per day. The lower part of the range is associated with northbound flow, and the upper part with southbound flow. From November through March, southbound flow is to be expected at the surface (see figure 33). From April through October, surface current reversals (northbound flow) may occur if runoff has been low and southerly winds have been prominent (see figure 34).

Bottom drift can be expected to be from 2 to 3nm per day. If the site is to be located in the Hudson Channel, the flow will generally be oriented with the channel axis. If it is found that the site is within the area of influence of the Hudson River outflow, the bottom, or replacement, flow will be directed toward the estuary, or northward. This will be especially apparent during high runoff, or in the spring and early summer. Offshore winds will cause upwelling along the coast and, therefore, a bottom drift towards shore. This onshore bottom drift will be evident west of the Hudson Channel. When these conditions do not prevail, a southbound bottom drift in the channel is to be expected in concert with the general drift of coastal water.

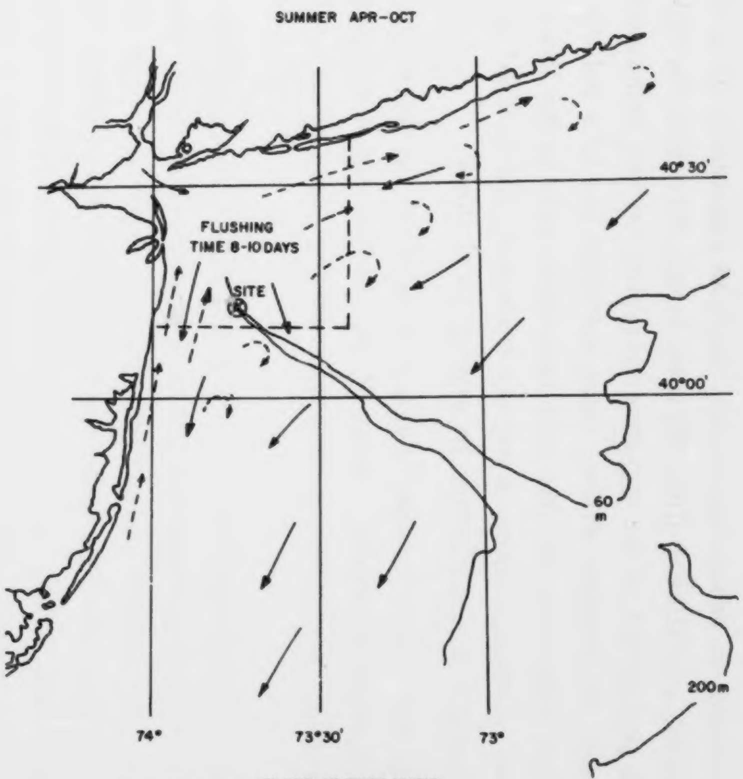
Although tidal currents will not produce any net drift, they will help the diffusion process. Tidal current speeds can be expected to vary from 0.2 to 0.5 knots in the tidal period of 12.4 hours, averaging 0.3 knots. A rotary tide is expected for an offshore site with its axis about parallel to the shoreline.


WINTER NOV-MAR
FLUSHING TIME 6-8 DAYS
SITE
40° 30'
40°00'
60 m
200m
74°
73°30'
73°

FLUSHING TIME = $\frac{\text{VOLUME OF RIVER WATER}}{\text{AVERAGE DAILY FLOW}}$

SPEEDS: INSHORE 3-5 MILES PER DAY
OFFSHORE 8-10 MILES PER DAY

Figure 33. Surface Flow During Winter Months -- November through March


SUMMER APR-OCT
FLUSHING TIME 8-10 DAYS
SITE
40° 30'
40°00'
60 m
200m
74°
73°30'
73°

FLUSHING TIME = $\frac{\text{VOLUME OF RIVER WATER}}{\text{AVERAGE DAILY FLOW}}$

SPEEDS: INSHORE 2-4 MILES PER DAY
OFFSHORE 4-6 MILES PER DAY

Figure 34. Surface Flow During Summer Months -- April through October

Bottom Characteristics

The sediments on the continental shelf of the New York Bight are fluvially deposited sands. The absence of fine material is due to the fact that the sediments have been reworked, causing removal of the fine portions, and are in equilibrium with the environment (Stetson, 1938). The shelf of the Bight presents an irregular surface of less than a 30-ft relief and an average slope of 0^{o} 03'. An erosional feature unique to this shelf is the Hudson Channel, cut by the Hudson River during a period of lower sea level, that extends from the mouth of the Hudson River to the head of the Hudson Canyon near the edge of the shelf, a distance of about 85 nm (shown in profile by figure 3). The average gradient of the channel thalweg (axis) is 0^{o} 04'. The present day channel appears as a series of troughs separated by low swells, the troughs having a relief of up to 120 ft (Uchupi, 1968). Some of these troughs provide deep water sites relatively close to the shore and are, therefore, potential power plant sites. Shepard and Cohee (1936) suggest that the channel may be a natural settling basin and, if so, it is expected that the sediments will be finer grained than those on the adjacent shelf. Sediment samples taken by Shepard and Cohee from the channel were analyzed as containing 35 percent 0.0312-mm sediment and 60 percent 0.0625-mm -- very fine silty sand. No engineering property measurements are available for channel sediments.

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BIOLOGICAL DESCRIPTION (LONG ISLAND AND BLOCK ISLAND SOUNDS)

Ecology

The New York, Long Island Sound (LIS) and Block Island Sound (BIS) area is adjacent to the large industrial and population center of New York-New Jersey, with potentially large future power requirements. The area is of interest biologically because it experiences a wide range of temperature. Consequently, the biota present is influenced by conditions ranging from subtropic to subarctic conditions, and its inhabitants are probably forms that are highly adaptable to changing environmental parameters.

The ecology is generally similar to that of the Gulf of Maine region.

Phytoplankton

The phytoplankton of the BIS and LIS areas have been investigated by Riley (1952), Riley and Conover (1967), and Conover (1956). The dominant phytoplanktonic species of the BIS area are given in table 27. The diatom, Skeletonema costatum, is the most dominant form, at times constituting 99 percent of the population. Thalassionema nitzschioides, Chaetocerus spp., and Leptocylindricus spp. are also present at times in large numbers.

The phytoplankton of LIS are given in table 28. As in BIS, Skeletonema costatum and Thalassionema nitzschioides are the dominant forms. Table 28 segregates the algae into three groups, those distributed throughout the sound (Group 1) representative of more tolerant forms, those distributed in the eastern end (Group 2) probably characteristic of oceanic species and species tolerant of oceanic conditions, and those distributed in the western end (Group 3) characteristic of inshore species and species tolerant of estuarine conditions.

The mean cell count of phytoplankton in LIS is given in table 29. Greatest numbers occur in the western and central portions of the sound, probably due to the influences of increased nutrients from land runoff contributed by rivers discharging into the sound.

Table 27. Dominant Species of Phytoplankton in Block Island Sound -- 1949 (from Riley, 1952)

Species	Number of Dates Present	Mean Number (cells/L)	Percentage of Total Population	Maximum Percentage of Population
Skeletonema costatum	12	270,500	83.5	99
Chaetoceros sp.	11	19,700	6.1	80
C. didymus	--	--	--	80
C. curvisetus	--	--	--	10
C. decipiens	--	--	--	12
C. compressus	--	--	--	13
Leptocylindricus sp.	8	6,900	2.1	45
L. danicus	--	--	--	40
L. minimus	--	--	--	5
Thalassiosira sp.	11	5,800	1.8	41
T. subtilis	--	--	--	41
Thalassionema nitzschioides	12	5,400	1.7	92
Nitzchia sp.	11	5,300	1.6	39
N. closterium	--	--	--	39
N. seriata	--	--	--	23
Asterionella japonica	10	1,700	0.5	7
Rhizosolenia sp.	12	1,500	0.5	11
R. faeroense	--	--	--	10
Guinardia flaccida	9	1,000	0.3	20

Table 28. Frequency of Occurrence of Phytoplanktonic Species in Long Island Sound (from Riley and Conover, 1967)*

Species	Race	Eastern Narrows	Central Basin	Western Basin	Western Narrows
Group 1					
Chaetoceros compressum	31	28	27	24	29
C. didymum	6	0	7	2	0
C. radians-C. tortissimum	19	9	20	10	35
Corethron criophilum	6	16	19	14	12
Coscinodiscus perforatus cellulosa	19	25	17	12	18
Leptocylindrus danicus	38	53	38	22	53
Paralia sulcata	63	63	60	65	53
Skeletonema costatum	75	88	76	69	94
Thalassiosira decipiens	69	38	41	37	82
T. gravida	62	53	64	59	64
Asterionella formosa	44	41	27	28	18
A. japonica	37	25	40	29	18
Thalassionema nitzschioides	87	91	80	80	76
Dinophysis acuminata	6	31	31	43	24
Peridinium trochoideum	63	62	55	53	59
Group 2					
Chaetoceros affine	6	12	4	6	0
C. curvisetum	0	16	5	2	0
C. danicum	31	22	11	0	0
Coscinodiscus centralis pacifica	0	12	6	0	0
C. radiatus	6	28	18	14	0
Ditylium brightwellii	6	25	8	0	0
Navicula distens	19	12	6	2	0
Nitzschia seriata	44	37	22	16	12
N. delicatissima	44	22	11	10	6
Pleurosigma normani	6	25	11	2	6
Thalassiothrix frauenfeldii	6	9	5	0	0
Group 3					
Chaetoceros debile	12	16	16	23	53
C. constrictum	0	6	6	4	12
Lithodesmium undulatum	0	3	7	14	29
Exuvella apora	6	9	15	26	6
E. baltica	0	3	5	6	12
Glenodinium pilula	19	0	19	37	29
Peridinium globulus	6	3	7	10	23
P. triquetum	6	3	14	12	29

*Frequency expressed as a percentage of the number of samples containing the species in relation to the total number of samples taken in the given area.

Table 29. Mean Cell Count (thousands/L) of Phytoplankton in Different Parts of Long Island Sound and at Maximum and Minimum Limits of Variation (from Riley and Conover, 1967)

	Race	Eastern Narrows	Central Basin	Western Basin	Western Narrows
Number of samples	16	32	98	49	17
Mean cell count	220	308	998	1,787	1,729
Minimum	31	46	22	17	87
Winter-spring maximum	720	750	14,100	11,300	7,320
May-June maximum	230	1,230	1,420	2,150	2,980
Autumn maximum	--	550	4,130	4,490	3,920

The seasonal abundance of phytoplankton is bimodal as shown by figures 35, 36, and 37 with winter and summer maxima, and the greater numbers in February. It is interesting to note that the peak abundance of phytoplankton at Georges Bank occurs in April rather than February.

Conover (1956) has shown that the numerical abundance of phytoplankton in LIS is greater inshore than offshore, but chlorophyll is uniformly distributed throughout the water column when all stations are averaged (figures 38 and 39).

In addition to the seasonal variation of total phytoplankton, there is a variation in the representative species in both BIS and LIS. The species variation of BIS is given by figure 40 for five representative algae. Skeletonema is present throughout the year, but peaks in February and July. Thalassiosira occurs only in the winter, while Leptocylindricus occurs largely during the summer months. Species variation of representative algae of LIS is shown by figure 41. Skeletonema and Thalassionema are present throughout the year with maximum abundance in February and March. Thalassiosira nordenskioldii and T. decipiens appear to be winter species, and T. gravida a summer-fall species.

The seasonal distribution of the major taxonomic groups of phytoplankton for LIS is shown in figure 42. Centrate diatoms constitute the bulk of the phytoplankton with maximal numbers in February. Small concentrations of dinoflagellates occur normally but are limited to the summer months only. At times, however, dinoflagellate blooms occur and reach concentration far greater than the diatoms.

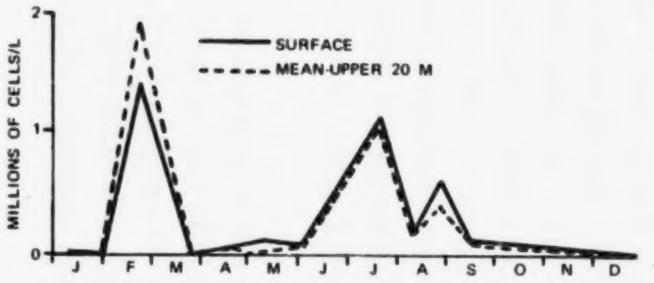

Figure 35. Seasonal Variation of Phytoplankton in Block Island Sound (from Riley, 1952)

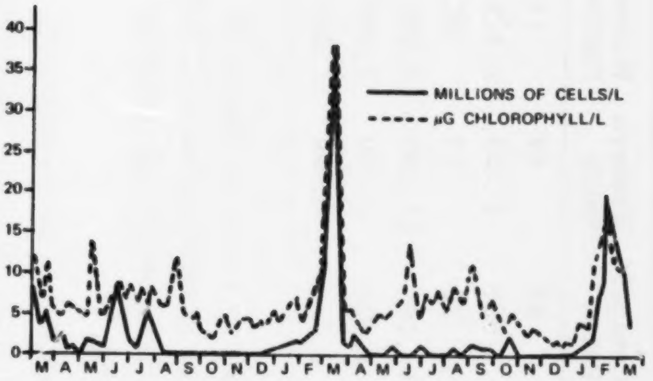

Figure 36. Phytoplankton and Chlorophyll in Long Island Sound -- Average Surface Values for all Stations (from Conover, 1956).

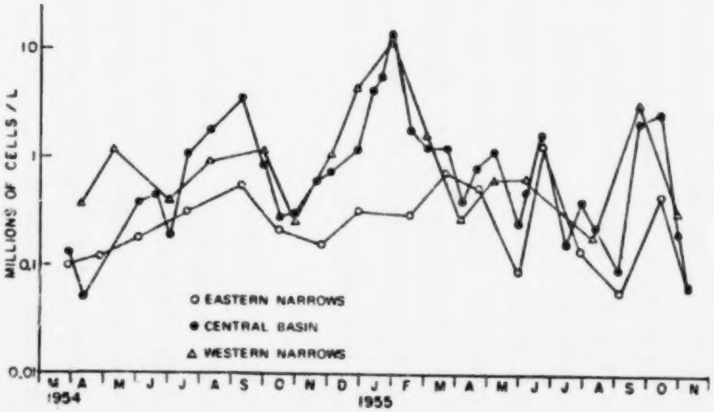

Figure 37. Seasonal Variations of Phytoplankton in Long Island Sound by Area (from Riley and Conover, 1967)

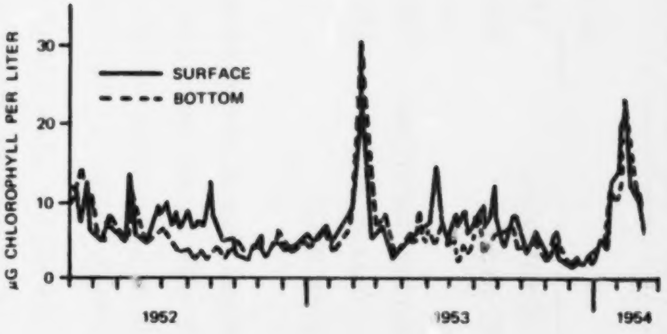

Figure 38. Distribution of Chlorophyll in Surface and Bottom Waters of Long Island Sound -- Average Values for All Stations (from Conover, 1956)

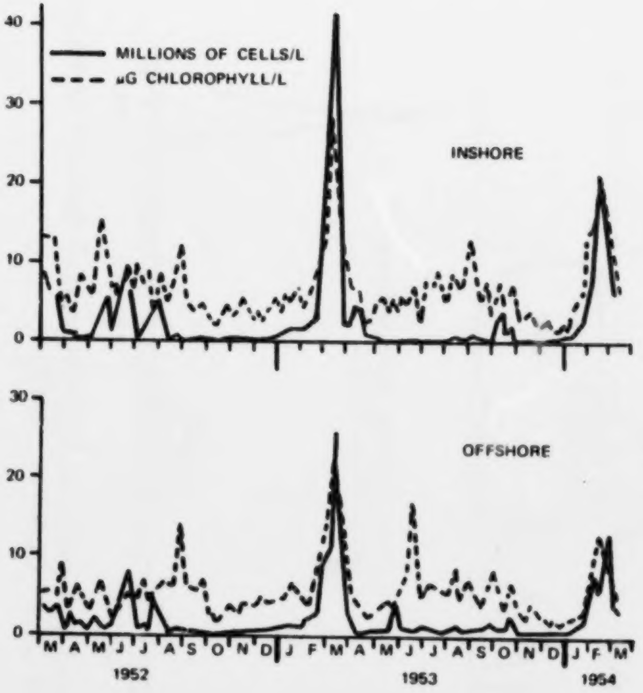

Figure 39. Phytoplankton and Chlorophyll Distribution at Inshore and Offshore Stations (from Conover, 1956)

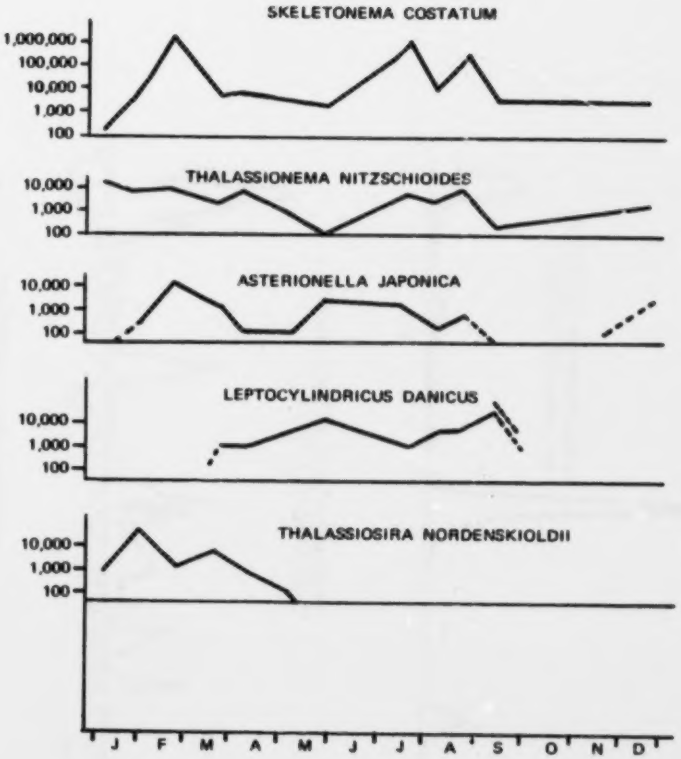

Figure 40. Seasonal Variation in Mean Values of Representative Phytoplanktonic Species in Block Island Sound (from Riley, 1952)

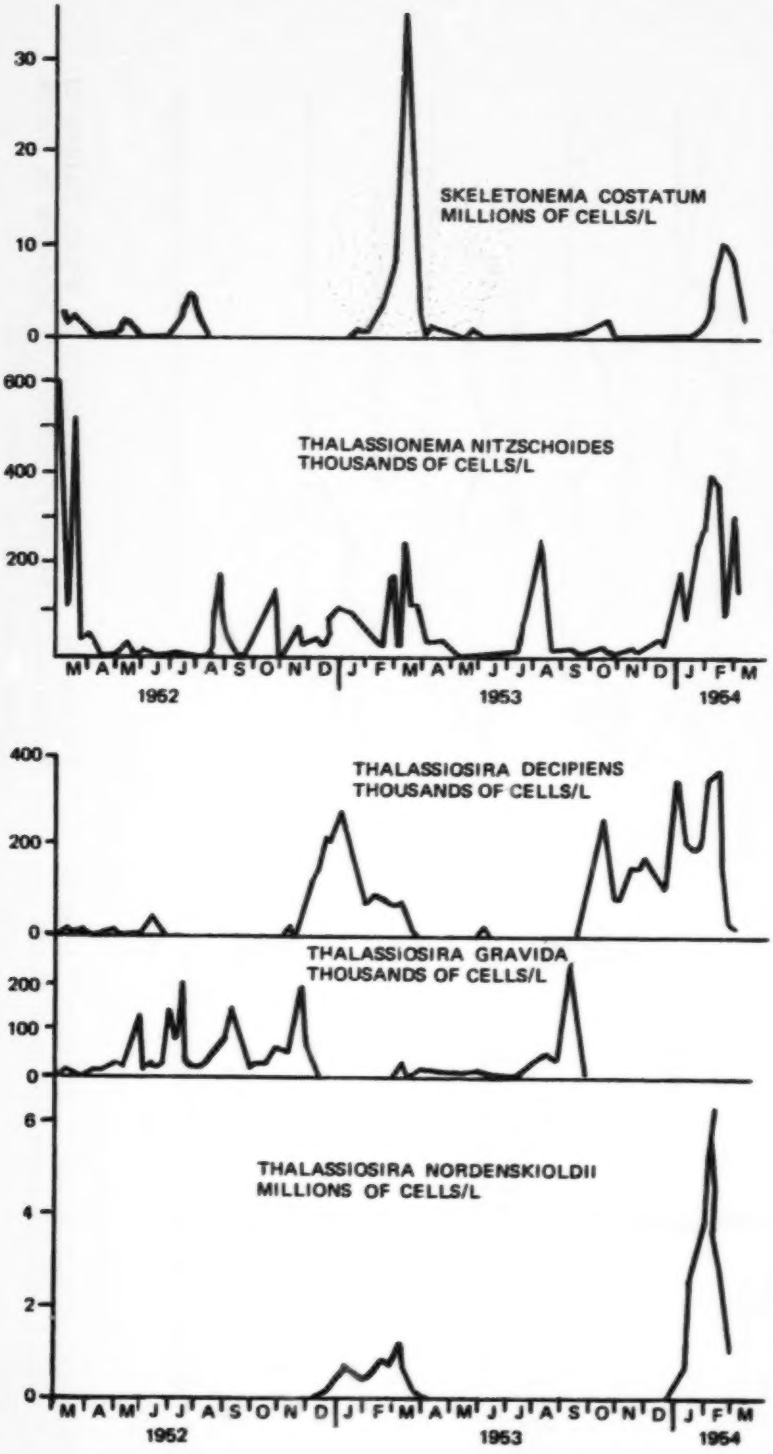

Figure 41. Seasonal Variation of Representative Species of Phytoplankton in Long Island Sound (from Conover, 1956)

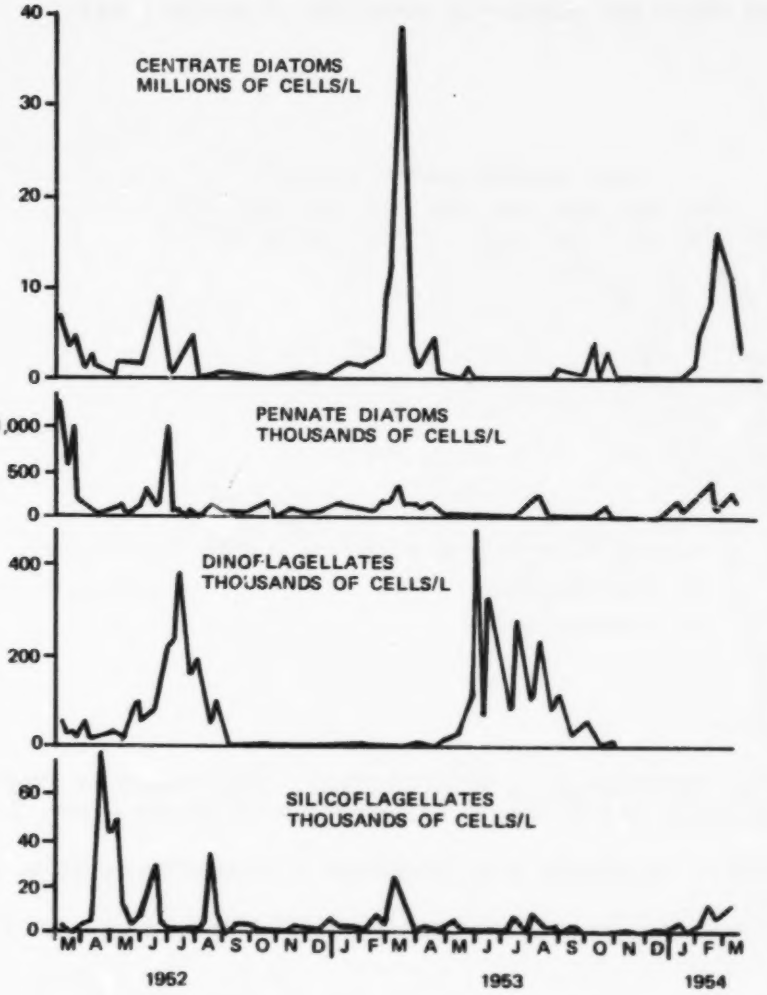

Figure 42. Distribution of the Major Taxonomic Groups in Long Island Sound, Averaged for All Stations (from Conover, 1956)

The vertical distribution of phytoplankton is limited to the photic zone of the water column. Light penetration in water varies with place, time, conditions, and water transparency. Riley (1939) gives the vertical distribution of plant pigments for tropical and temperate waters (figure 43). Vertical distribution of plant pigment does not extend much beyond 50 meters except in tropical waters. Riley (1952) determined three phytoplankton depth profiles for BIS (figure 44). During the February maxima of phytoplankton, greatest concentrations occur just below the surface at about the 10 meter mark.

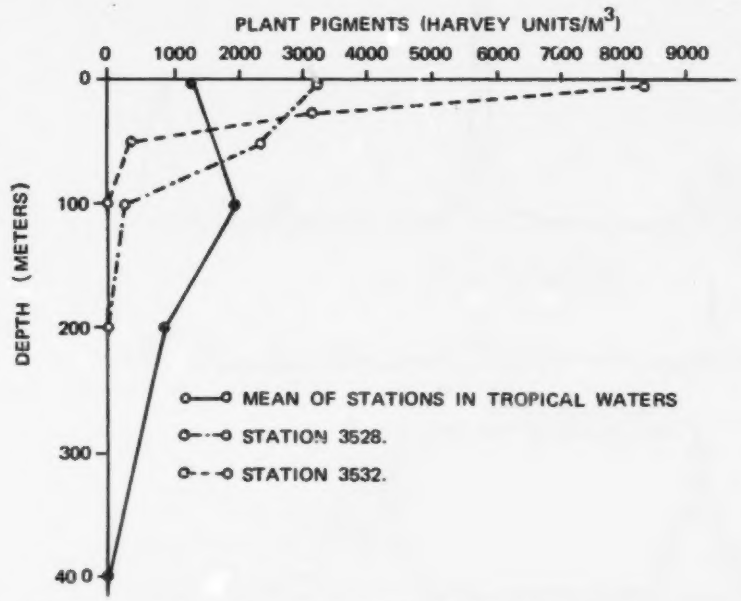

Figure 43. Vertical Distribution of Phytoplankton, Expressed as Plant Pigment Units, in Northern and Tropical Atlantic Waters (from Riley, 1939)

Station 3532 -- southeast of Long Island (North Atlantic slope water)

Station 3528 -- deeper water, transitional between slope and tropical water.

Tropical Stations -- Sargasso Sea, Cuba, Florida Straits

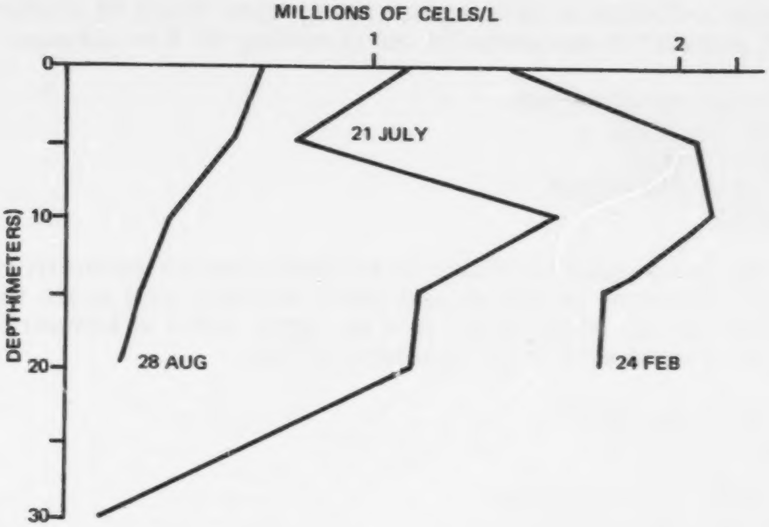

Figure 44. Vertical Distribution of Phytoplankton in Block Island Sound (from Riley, 1952)

The phytoplankton of LIS were compared with those found in other New England waters (Gulf of Maine, Woods Hole, BIS) by Riley and Conover (1967). Some of their comparisons are as follows:

1. Dominant species with peaks of abundance similar to LIS.

   *Skeletonema costatum**
   Thalassionema nitzschioides
   Paralia sulcata

2. Less dominant species with peaks of abundance similar to LIS.

   Cerataulina pelagicus
   Chaetoceros radians
   Leptocylindrus canicus
   Nitzschia longissima
   Thalassiosira gravida
   Thalassiosira rotula
   Peridinium trochoideum
   Distephanus speculum
   Ebria tripartita

3. Less dominant species with peaks of abundance which do not coincide with LIS.

   Chaetoceros curvisetum
   C. decipiens
   Prorocentrum scutellum

---

*Ranking species of LIS, BIS, and inshore Gulf of Maine

4. Spring and summer forms in deep open areas; when found in shallower areas the peak population occurred in early spring or late autumn.

   Chaetoceros compressum
   Guinardia flaccidia
   Lauderia borealis
   Rhizosolenia delicatula
   R. setigera

5. Peak populations in the Gulf of Maine in summer; but in southern New England waters, flowered in spring and early summer and again in September. This group throught to have an upper limit of temperature tolerance which is exceeded in the southern areas.

   Asterionella japonica
   Chaetoceros debile
   Nitzschia seriata
   Rhizosolenia fragellissima
   Thalassiosira decipiens

6. Forms with no autumn peak in the southern region.

   Thalassiosira nordenskioldii

7. Species found in LIS only.

   Schroderella delicatula
   Euxuviella apora
   Goniauxlax minime
   Prorocentrum triestinum

Growth coefficients for several algal types found in the BIS-LIS region are given in table 30A. The growth coefficient, k, for S. costatum ranged from 1.230-0.15 during the period of February and March. Fogg (1965) gives a k value for S. costatum of 0.55. Highest growth coefficients for Thalassiosira occur at low temperature, indicating that it is a cold water species (table 30B).

The primary production of the LIS and continental shelf waters off New York has been reported by Ryther and Yentsch (1958). Their summary is shown in table 31. The rate of carbon fixed (gm C/m^2) decreases with depth. Daily production ranged from 0.2-1.00 gm C/m^2/day.

Table 30. A) Growth Coefficients in Bottles of Surface Water for Several LIS Algae, B) Growth Coefficients as Function of Temperature (from Riley and Conover, 1967; Riley, 1961)

(A)	Feb 2-5	Feb 24-Mar 3	Mar 24-30
Skeletonema costatum	1.23	0.15	0.17
Thalassiosira nitzschiodes	0.40	0.003	-0.20
T. nordenskioldii	0.48	-0.07	--
Asterionella japonica	0.86	0.12	--
Chaetocerus sp.	--	--	-0.17
Leptocylindricus danicus	--	--	0.12

	Temperature (°C)	Skeletonema	Thalassiosira
(B)	1.7	-0.021	0.058
	1.7	-0.025	0.015
	5.0	0.144	-0.133
	8.0	0.258	-0.163

Table 31. Annual Rate of Carbon Fixation (from Ryther and Yentsch, 1958)

	Depth (m)	gm C/m^2 of Sea Surface
Long Island Sound	25	380
Continental Shelf	25-50	160
	50-1000	135
	1000-2000	100

Zooplankton

The zooplankton of the New York-Long Island Sound area have been studied by Deevey (1952a, 1952b, 1956) and Grice and Hart (1962). As in the Maine and Florida regions, copepods are the dominant zooplankton throughout the year when measured either numerically or by displacement volume. Chaetognaths constitute the second most abundant group according to Grice and

Hart (1962). Salps, cladocerans, medusae, appendicularians, euphausiids, amphipods, decapods, and ctenophores may also be seasonally prominent (Grice and Hart, 1962; Deevey, 1952a). Grice and Hart (1962) found a thirty-fold difference between the maximum mean volume during the warm months (3.71 cc/m^3) as compared to the cold months (0.12 cc/m^3) in neritic waters, while Clarke (1940) and Deevey (1956) have reported differences of 20-40 and 13 fold, respectively. (See table 32 for monthly determinations by Deevey.)

Table 32. Mean Monthly (Zooplankton) Total Numbers and Displacement Volumes in Long Island Sound, 1952-1953--Mean of All Stations (from Deevey, 1956)

	Number per m^3	Volume per m^3 (mL)
Mar	25,675	1.21
Apr	44,255	1.26
May	111,200	1.92
June	161,385	1.12
July	77,000	1.00
Aug	114,715	3.37
Sept	105,140	2.70
Oct	31,180	0.23
Nov	31,350	0.24
Dec	14,325	0.21
Jan	10,635	0.26
Feb	19,560	0.37
Mar	45,940	--
Apr	53,430	0.80
May	76,870	0.39

The displacement volume and numerical abundance of zooplankton as a function of season at stations on a transect from Montauk Point, New York to Bermuda is given by figure 45. The data show that regardless of season there are generally larger quantities of zooplankton in shelf waters as compared to slope, Gulf Stream, or Sargasso Sea waters. The mean zooplankton displacement volume for Long Island neritic waters found by Deevey (1.07 mL/m^3) agrees very well with that of Grice and Hart, but differs numerically by about 60 times. The discrepancy apparently lies in the relative size of the zooplankton caught as shown by Deevey's comparison of Georges Bank, BIS, and LIS zooplankton hauls (figure 46). Many species of zooplankton on Georges Bank are known to be very large. Numerical and dry weight relationships of various zooplankton samples are given in table 33.

The percentage composition and numerical seasonal abundance of zooplankton groups for BIS waters are shown by figure 47 and table 34. The data show that copepods are the most abundant group and are present year-round, as at stations off Long Island Sound. Cladocera are abundant in the early summer and doliolids, appendicularians, coelenterates, and larvae of various bottom invertebrates are abundant during the summer months.

Table 33. Numerical and Dry Weight Relationships Between Various Zooplankton Hauls (from Deevey, 1952)

Date	Net No.	Dry Weight (mg/m^3)	Number/ (m^3)	Ash (mg/m^3)
Jan 11	10	74.6	28,540	10.4
11	2	29.6	4,800	2.2
Feb 3	2	3.6	420	0.8
24	2	44.6	5,140	3.2
Mar 24	2	8.6	720	2.5
Apr 9	2	0.7	840	0.1
May 7	2	0.0	100	--
June 2	2	10.2	4,300	1.4
July 21	2	31.8	1,480	11.3
Aug 9	2	39.7	7,125	5.9
Aug 28	2	34.8	7,115	4.6
Sept 17	2	24.0	1,890	5.9
Oct 6	10	62.9	27,800	18.8
Dec 19	2	4.5	350	2.2

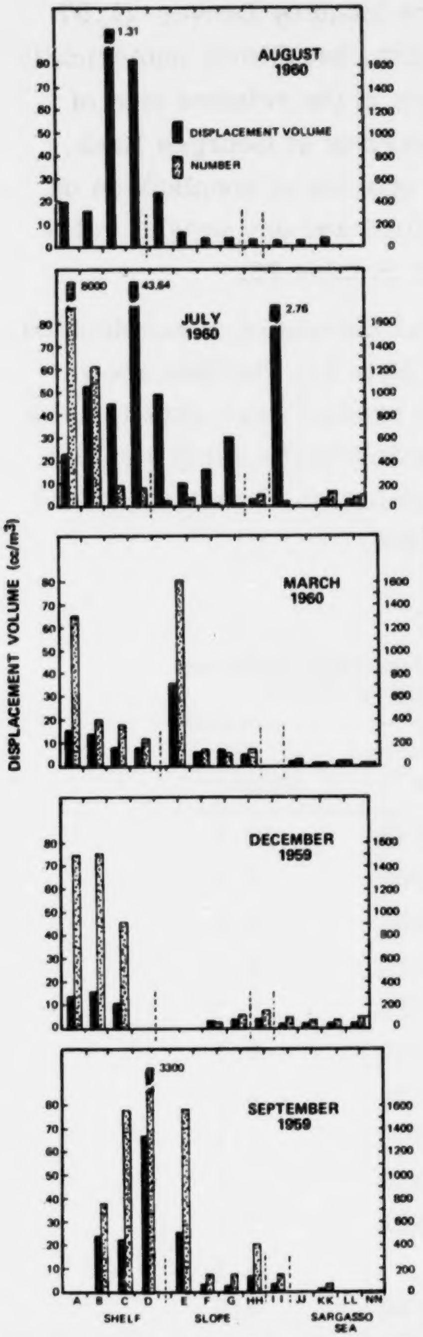

Figure 45. Displacement Volumes and Numerical Abundance of Zooplankton (from Grice and Hart, 1962) In July, station JJ is in slope water, not Sargasso Sea.

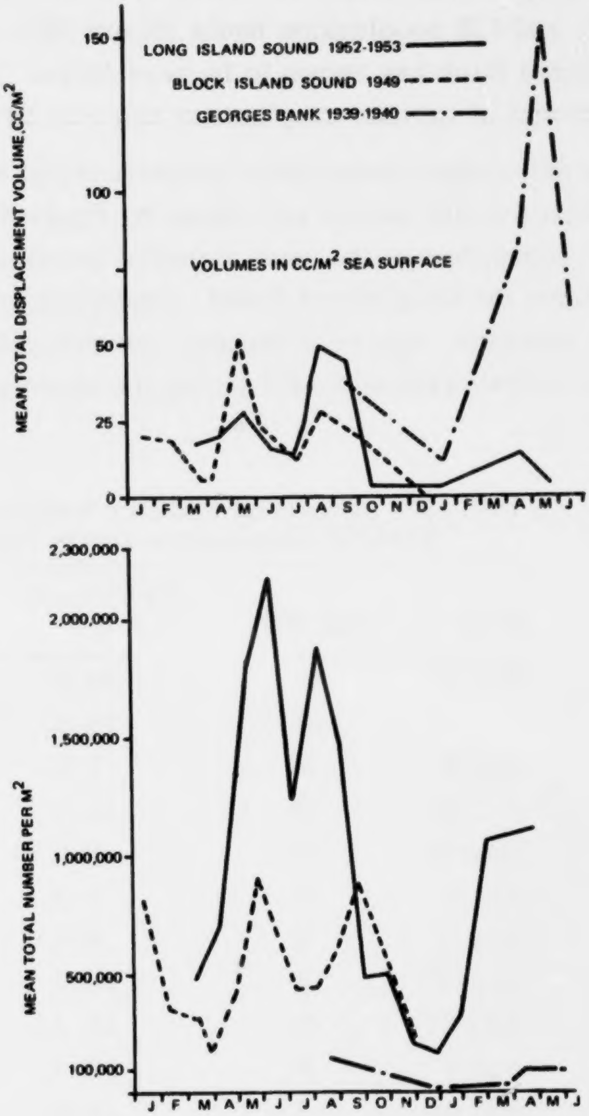

Figure 46. Mean Monthly Zooplankton Displacement Volumes and Total Numbers Recorded from Long Island Sound, and Georges Bank (from Deevey, 1956)

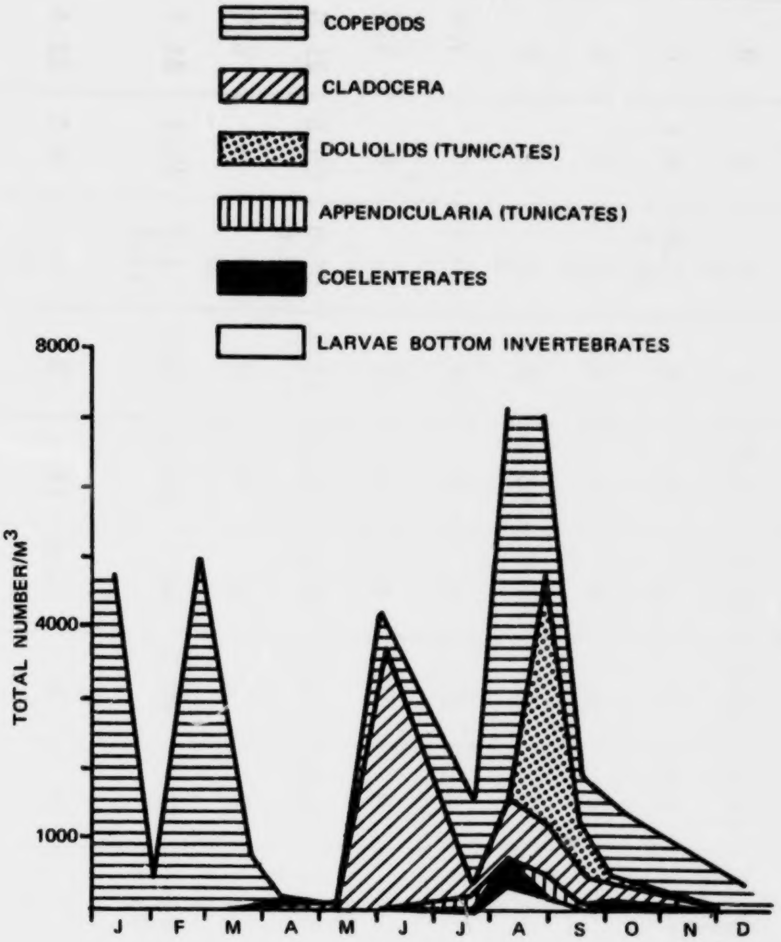

Figure 47. Major Groups of Zooplankton (Deevey, 1952)

Table 34. Percentage of Zooplankton in Samplings (from Deevey, 1952)

			A. Percentage in No. 10 Net Samples								
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Dec
Copepoda											
Pseudocalanus minutus	28.6	65.3 10.0	10.1	25.1	10.4	5.5	0	0 0	0	0	0
Centropages typicus	7.6	12.4 1.0	1.7	0	0	0	0	5.9 16.1	3.1	0	0
C. hamatus	0	0 0	0	0	0	0	9.7	0 0	0	0	0
Temora longicornis	0	0 0	0	0	10.0	18.5	0	0 0	0	0	0
Acartia tonsa	0	0 0	0	0	0	0	12.6	15.4 0	0	7.5	0
Paracalanus crassirostris	0	0 0	0	0	0	0	0	0 0	0	5.8	33.6
Oithona similis	19.9	31.0 7.3	11.0	9.8	16.3	11.4	35.4	51.0 10.6	16.5	21.5	48.8
Microsetella norvegica	0	0 0	0	0	0	0	0	0 0	0	5.7	0
Copepod nauplii	41.3	42.5 25.1	74.1	47.1	48.0	37.1	8.0	4.6 11.3	41.4	21.7	7.3
Bivalve Larvae											
Lamellibranch veligers	0	0 0	0	0	5.4	12.4	0	0 0	8.5	22.0	0
Tunicata											
Oikopleura dioica	0	0 0	0	0	0	0	21.4	3.7 10.2	8.1	0	0
Doliolum nationalis	0	0 0	0	0	0	0	0	0 31.3	4.6	0	0

Table 34 (Cont'd)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec
Doliolum gengenbauri	0	0 0	0	0	0	0	0	0 0	5.7	0	0
Miscellaneous	2.6	4.1 1.3	3.1	18.0	9.9	15.1	12.9	13.4 20.5	12.1	15.8	10.3
	B. Percentage in No. 2 Net Samples										
Copepoda											
Pseudocalanus minutus	68.0	72.0 94.3	73.5	6.9	28.4	5.2	0	3.2 1.0	0	0	0
Centropages typicus	33.5	26.0 2.0	4.1	3.0	0	0	17.0	6.3 6.3	20.9	7.6	38.2
C. hamatus	7.5	0 0	0	5.4	0	0	35.0	0 0	0	0	0
Acartia tonsa	7.4	0 0	0	0	0	0	12.4	47.2 19.7	0	32.8	4.0
Temora longicornis	0	0 0	0	7.8	19.3	19.2	2.5	0 0	0	0	4.0
Oithona similis	0	0 0	0	9.2	5.0	0	0	0 0	0	0	0
Paracalanus parvus	0	0 0	0	0	0	0	0	13.3 4.2	0	0	3.9
Oncaea venustus	0	0 0	0	0	0	0	0	0 0	4.2	8.1	0
Corycaeus speciosus	0	0 0	0	0	0	0	0	0 0	0	0	19.5
C. venustus	0	0 0	0	0	0	0	0	0 0	0	0	7.3

Table 34 (Cont'd)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Dec
Bryozoa											
Cyphonautes larvae	0	0 0	0	0	7.2	0	0	0 0	0	0	0
Coelenterata											
Hydra medusae	0	0 0	5.8	3.5	14.3	0	0	4.4 0	0	0	0
Tunicata											
Fritillaria borealis	0	0 0	6.7	54.0	0	0	0	0 0	0	0	0
Oikopleura dioica	0	0 0	0	0	0	0	11.4	0 0	4.4	0	0
Doliolum nationalis	0	0 0	0	0	0	0	0	0 45.7	18.9	0	0
Dolioletta gengenbauri	0	0 0	0	0	0	0	0	0 3.7	14.5	0	0
Cladocera											
Podon leuckarti	0	0 0	0	0	6.9	20.3	0	0 0	0	0	0
P. intermedius	0	0 0	0	0	0	0	11.0	11.6 0	0	6.4	0
Evade nordmanni	0	0 0	0	0	0	45.0	0	0 0	0	0	0
Penilia aviroostris	0	0 0	0	0	0	0	0	0 9.1	20.3	9.1	0
Miscellaneous	3.6	2.0 3.7	9.9	10.2	18.9	10.3	10.7	14.0 10.3	16.8	36.0	23.1

Copepods

Pseudocalanus minutus and Centropages typicus are widely distributed and generally dominant in Long Island waters as shown in tables 34, 35, and 36. However, many different species may be locally prominent depending on the season (figure 47) and water circulation. The numerical abundance of P. minutus and C. typicus by month is shown in figures 48 and 49. The data show the P. minutus as least abundant in the fall while C. typicus is least abundant in the spring. A similar relationship is shown for Acartia clausi and A. tonsa by figure 50. Such data indicate that various species of zooplankton apparently succeed one another seasonally, as do various species of phytoplankton.

Sanders (1952) has found C. typicus to be more abundant in surface plankton tows and P. minutus in bottom tows. Apparently, however, no studies have been conducted on the vertical distribution of copepods or on their diurnal migration in this area.

Table 35. Composition of the Zooplankton in Samples Taken February 17, 1951 (from Sanders, 1952)

	Plankton (tows)	
Species	Surface %	Bottom %
Copepoda		
Pseudocalanus minutus	47.01	91.28
Centropages typicus	29.74	2.01
Oithona similis	2.20	4.69
Temora longicornis	1.65	--
Calanus finmarchicus	2.20	--
Acartia tonsa	1.65	--
Clytemnestra rostrata	0.55	--
Chaetognatha		
Sagitta elegans	1.10	--
S. elegans (eggs)	0.55	--
Bryozoa		
Cyphonautes larvae	4.40	0.68
Polychaeta		
Polychaete larvae	1.10	--
Gastropoda		
Gastropod larvae	9.35	--
Cirripedia		
B. balanoides (cyprids)	0.55	--

Table 36. Numerically Important Copepod Species in Neritic, Slope, Gulf Stream, and Sargasso Sea Waters (from Grice and Hart, 1962)

Species	Frequency	Mean Number per m^3
Neritic (14 samples)		
Pseudocalanus minutus	13	559
Centropages typicus	14	450
Oithona similis	13	151
Temora longicornis	8	59
Paracalanus parvus	8	39
Calanus finmarchicus	11	32
Metridia lucens	12	16
Candacia armata	9	9
Slope (15 samples)		
Centropages typicus	11	76
Pseudocalanus minutus	8	16
Oithona similis	6	14
Metridia lucens	11	15
Clausocalanus pergens	6	19
C. arcuicornis	7	13
Pleuromamma borealis	8	6
Oithona atlantica	12	6
Gulf Stream (3 samples)		
Clausocalanus furcatus	3	27
Lucicutia flavicornis	3	9
Oithona plumifera	3	9
O. setigera	3	7
Calocalanus pavo	2	9
Faranula gracilis	3	4
Mecynocera clausi	3	2
Sargasso Sea (11 samples)		
Clausocalanus furcatus	9	7
Oithona setigera	11	6
Lucicutia flavicornis	11	4
Ctenocalanus vanus	6	3
Farranula gracilis	6	2
Mecynocera clausi	9	2

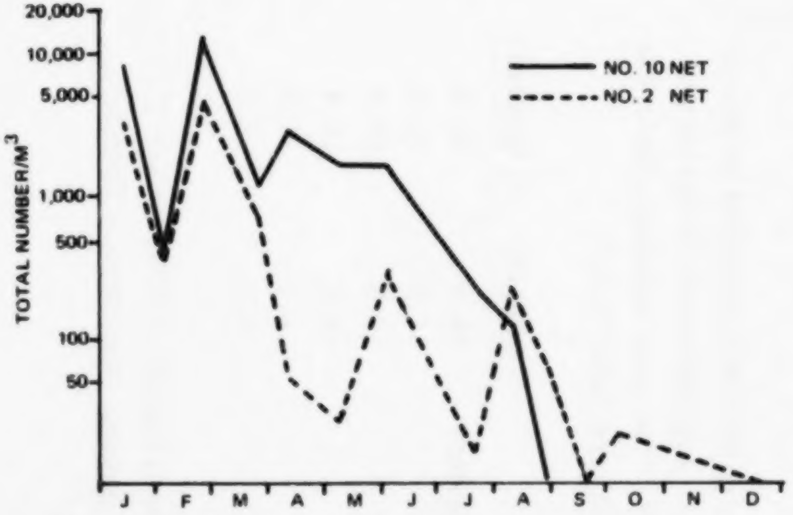

Figure 48. Numerical Abundance of Pseudocalanus minutus (from Deevey, 1952)

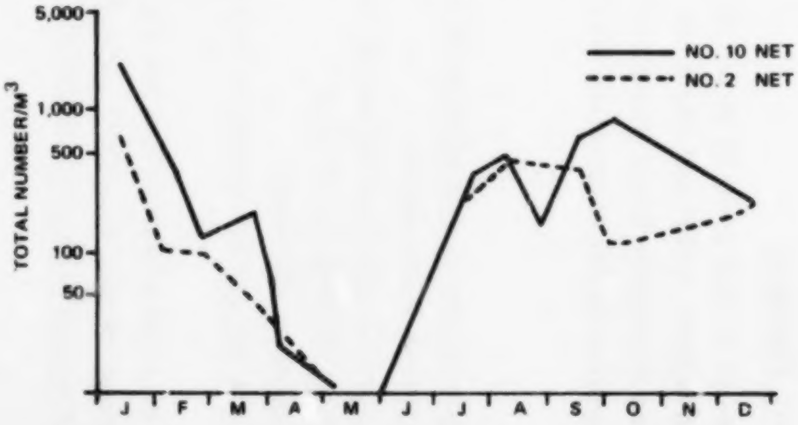

Figure 49. Numerical Abundance of Centropages typicus (from Deevey, 1952)

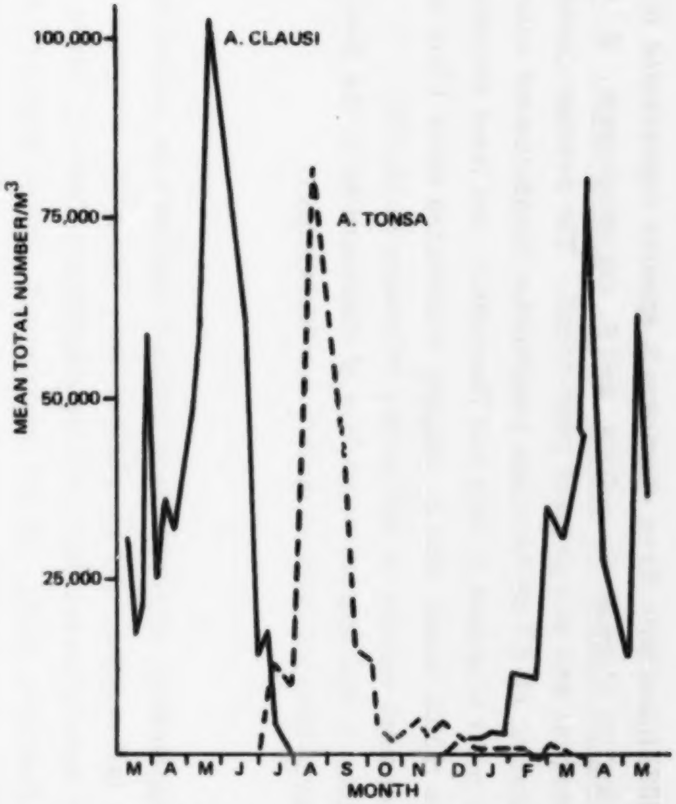

Figure 50. Numerical Abundances of Acartia clausi and A. tonsa (from Deevey, 1956)

Chaetognaths

Grice and Hart (1962) found only three chaetognath species represented in shelf collections, Sagitta elegans, S. enflata, and S. serratodentata. S. elegans was most numerous and was present year-round. The average abundance was 25/m^3, constituting 14.6% of the mean zooplankton displacement volume. Chaetognaths were most abundant in July and December, and least abundant in March. Sanders (1952) found that S. elegans constituted about 1% of the zooplankton displacement volume in BIS during February (table 35). The vertical distribution and diurnal migration of chaetognaths in the New York-Long Island area have not been studied to our knowledge.

Other Zooplankton

Other groups of zooplankton, observed in significant numbers primarily during the summer or fall months, include cladocerans, tunicates, coelenterates, and larvae of other invertebrates that are meroplanktonic (Deevey, 1952a, 1952 b, 1956, and Sanders, 1952). Of the cladocerans, Podon intermedius and P. polyphemoides were common, and also the tunicate Oikopleura dioica.

Principal Fisheries

The species of fish present in the BIS-LIS area have been reported by Merriman and Warfel (1948) and Richards (1963a). Approximately 40 species of fish were commonly found (tables 37 and 38). The most abundant fish of the area reported by Merriman and Warfel (1948) are listed here:

	% (weight)	% (number)
Pseudopleuronectes americanus (winter flounder)	36.5	41.8
Raja erinacea (little skate)	17.9	11.2
Myoxocephalus octodecimspinosus (sculpin)	13.3	20.8
Merluccius bilinearis (whiting)	6.3	10.4
Raja diaphanes (big skate)	4.5	1.2
Lophosetta aquosa (windowpane flounder)	4.4	5.6

The three most abundant species reported by Richards (1963a) include P. americanus (winter flounder); Scopthalmus aquosus (windowpane flounder), and Merluccius bilinearis (whiting).

The chief residents include all of the above, with the winter flounder forming the most conspicous species present. The common migrants found in the area include *Stenotomus chrysops* (porgy), *Ammodytes americanus* (sand eel), and *Brevoortia tyrannus* (menhaden). The standing crop of demersal fish for LIS is reported to be 0.76 gm/m^2 (Richards, 1963a). The Fishery Statistics (1969) lists the winter flounder as an important fishery of the New England area, with an annual catch of about 21 million pounds valued at about 2.2 million dollars.

Table 37. Names of Fishes Taken in Monthly One-Hour Hauls, and Additional Species Observed in Other Hauls on Collection Dates from 1943-1946 (from Merriman and Warfel, 1948)

From Monthly One-Hour Hauls

1. Mustelis canis: smooth dogfish, gray fish
2. Squalus acanthias: spiny dogfish, gray fish, piked dogfish
3. Raja erinacea: little skate, common skate, hedgehog skate, summer skate
4. Raja diaphanes: big skate, spotted skate, winter skate
5. Raja stabuliforis: barn door skate, winter skate
6. Clupea harengus: herring, sardine
7. Pomolobus pseudoharengus: alewife, gaspereau, sowbelly
8. Porontotus triacanthus: butterfish, dollar fish, harvest fish
9. Centropristes striatus: sea bass, black sea bass, blackfish
10. Stenotomus chrysops: scup, porgy
11. Menticirrhus saxatilis: king fish, king whiting, whiting
12. Tautogolabrus adspersus: cunner, sea perch, bergall, nipper
13. Tautoga onitis: tautog, blackfish
14. Stenphanolepis hispidus: common filefish, fool fish, thread file fish
15. Spheroides maculatus: puffer, swell fish, blowfish, globe fish
16. Myoxocephalus octodecimspinosus: longhorn sculpin, gray sculpin, hacklehead, toadfish
17. Hemitripterus americanus: sea raven, red sculpin
18. Prionotus carolinus: common sea robin, green eye
19. Prionotus evolans: redwinged sea robin, stripped sea robin
20. Macrozoarces americanus: ocean pout, eel pout, yowler, conger eel, ling
21. Merluccius bilinearis: whiting, silver hake, New England hake
22. Gadus morhua: cod, rock cod
23. Melanogrammus aeglifinus: haddock, white-eye
24. Urophycis regius: spotted hake
25. Urophycis tenuis: white hake, Boston hake, mud hake, ling
26. Urophycis chuss: squirrel hake, snot-head hake
27. Paralichthys dentatus: summer flounder, fluke, plaice, turbot
28. Paralichthys oblongus: four-spotted flounder, Baptist fish
29. Limanda ferruginea: yellowtail, rusty dab, sand dab
30. Pseudopleuronectes americanus: winter flounder, flat, blackback, flounder

Table 37 (Continued)

31. Glyptocephalus cynoglossus: witch flounder, sole, fluke
32. Lophopsetta aquosa: sand flounder, window pane, sun dial
33. Lophius americanus: goose fish, monk fish, angler, mouth-all-mighty, fishing frog

From Additional Hauls on Collection Dates

1. Dasybatus marinus: stingray, stingaree. clam cracker, IX-12-43
2. Brevoortia tyrannus: menhaden, pogy. IX-10-44
3. Scomber scombrus: common mackerel. VI-23-44
4. Cynoscion regalis: weakfish, squeteague, sea trout. X-31-43, XI-19-44, X-15-45
5. Leiostomus xanthurus: spot, goody, post croaker, lafayette, porgy, yellowtail. XI-19-44.
6. Ceratacanthus schoepf: orange filefish, fool fish, sunfish. X-26-44
7. Neoliparis atlanticus: sea snail, lumpsucker, New England sea snail. IV-16-45
8. Liparis liparis: sea snail, striped sea snail, north Atlantic sea snail. IX-14-46.
9. Pholis gunnellus: rock eel, gunnel, butterfish. V-18-44, III-24-46
10. Pollachius virens: pollack, Boston bluefish, coafish, green cod. VI-23-44
11. Microgadus tomcod: tomcod, frost fish. III-19-44

Table 38. Common Fish Species Found at Two Stations in Long Island Sound in July (from Richards, 1963a)

Species	Station 1, 1956		Station 2, 1957	
	Total Number	Total Weight (g)	Total Number	Total Weight (g)
Raja erinacea	35	11,430	12	--
Clupea harengus	7	4	24	163
Alosa pseudoharengus	9	73	0	--
Alosa aestivalis	2	4	1	4
Brevoortia tyrannus	29	116	1	11
Anchoa mitchill	4	63-76	23	--
Osmerus mordox	2	52	1	51
Conger oceanica	1	19	0	--
Merluccius bilinearis	106	2,911	310	13,519
Pollachuis virens	2	1	0	--
Enchelyopus cimbrius	1	68	18	1,031
Urophycis chuss	19	437	99	8,552
Urophycis regius	15	335	23	792
Apeltes quadracus	4	6	0	--
Syngnatus fuscus	9	9	3	4
Menidia menidia	33	100	3	12
Cynoscion regalis	0	--	48	107

Table 38 (Cont'd)

Stenotomus chrysops	313	1,976	24	1,029
Centropristes striatus	25	17	0	--
Gobiosoma ginsburgi	1	4	0	--
Tautogolabrus adspersus	44	4,642	45	6,045
Tautoga onitis	16	3,556	5	3,530
Ammodytes americanus	320	1,373	0	--
Pholis gunnellus	3	13	0	--
Poronotus triacanthus	3	5	5	52
Prionotus carolinus	143	1,104	23	59
Prionotus evolans	3	549	1	339
Myoxocephalus aeneus	20	606	0	--
M. octodecimspinosus	4	705	1	65
Paralichthus oblongus	8	218	19	795
Paralichthus dentatus	3	1,500	2	1,100
Scophthalmus aquosus	132	15,296	15	12,837
Etropus microstomus	12	76	0	--
Pseudopleuronectes americanus	965	105,232	796	97,444
Trinectes maculatus	2	--	0	--
Sphaeroides maculatus	40	241	0	--
Lophius americanus	2	6,800	1	--

The Statistical Bulletin for 1968 (ICNAF, 1970) lists the nominal catch for the winter flounder in an area from Long Island to Chesapeake Bay as 72 metric tons. However, if an area up to Cape Cod is included, the catch would be increased to some 3,886 metric tons. Therefore, the winter flounder (P. americanus) of LIS-BIS is a fishery of some commercial importance.

In a study of the Connecticut commercial fisheries, a steady decline in the fishing industry was noted (Electric Boat, 1968). However, factors other than productivity of the fisheries are responsible.

The distribution of lobster larvae for the southern New England coast has been reported by Lund and Steward (1970). Their study indicated that lobster larvae are widely distributed in offshore waters, but in Long Island Sound, the largest concentrations were observed at the western end. They concluded that surface current patterns peculiar to LIS were responsible for the increased numbers at the western end, and the lower concentrations observed in the eastern end and at BIS were caused by a flushing phenomenon and subsequent dilution in the offshore water.

Important Fisheries of the LIS-BIS Area

Common Name	Catch* (metric tons)	New England Fishery** Weight (1,000 lb)	Value ($1,000)
Sea scallop	16,727	7,025	5,438
Yellowtail flounder	10,410	52,387	5,460
Ocean pout	8,719	1	1
Sculpin	6,687	not listed	
Winter flounder	3,958	21,252	2,295

*ICNAF, 1970 - for areas 6A and 5Zw (South Long Island, Block Island, and Cape Cod areas) based on 1968 catches.

**Data from Fishery Statistics, 1967, for new England Fishery Resources (Lyles, 1969)

The important fisheries for area 6A and 5Zw (ICNAF, 1970) listed in order of greatest catches are tabulated above. Areas 6A and 5Zw include the inshore area from southern NewJersey to Cape Cod. The sea scallop and the yellow-tail flounder are the most abundant species encountered and represent a fishery valued at about 11 million dollars in the New England area. The winter flounder discussed earlier is also a species important in this area, as is the ocean pout. The sculpin (a trash fish) is primarily used for processing. A description of each of these forms is given in tables 39 through 43.

The potential of a surf clam and an ocean quahog fishery in this area has been reported by Merrill and Ropes (1969), and Merrill et al (1969). The area of largest potential was found off the Long Island, New York, and the New Jersey coasts (figures 51 and 52). The surf clam (Spisula solidissima) and the ocean quahog (Artica islandica) were found in average depths of 29 and 42 m, respectively. Except for a small fishery off the coast of Rhode Island, the ocean quahog has not been fished commercially. The surf clam is fished commercially in waters off the coast of the Mid-Atlantic states. Landings for the New England fishery in 1967 were reported to be 45 and 16 thousand pounds, respectively (Lyles, 1969). The larger surf clam found at shallower depths has been utilized more as a fishery than the ocean quahog. The population of black quahogs in the area could furnish catches of substantial value if the species were in demand commercially (Parker, 1966).

Table 39. Details on the Sea Scallop Fishery

Sea scallop *Plecopecten magellanicus*

Characteristics		Data Source*
Commercial landings and economic importance	New England: 7,025,000 lb ($5,438,000)	1
	New Bedford boats (25 trips/yr): 250,000 lb ($130,000)	2
	17,667 metric tons (5Y-940, 5Zw-467, 6A-16,260)	3
	rank is 1 in 6A, 4 on Atlantic coast, 11 in U.S.	1
Geographical range	from north shores of Gulf of St. Lawrence to Cape Hatteras	2,4
Habitat preferences		
Water depth	in north: just below low-tide mark; south of Cape Cod: deeper, colder water, 20-50 fathoms	2
Temperature range	optimum 46°F	4
Type of bottom	gravel, sand, sand-mud	4
Food sources		
Fry	plankton	
Adults	plankton	
Growth	9 in. max at 10 yr, average 6 in. 1-1/2 yr 5-12 mm, 2-1/2 yr 2.2 in., 4-1/2 yr 3.5 in., 6-1/2 yr. 4.4 in.	4
Mobility migration		
Horizontal	no measurable migration; larger than 4 in. do not swim	4
Behavioral characteristics	found largely in beds	4
Spawning		
Time of year	August to October	
Position of eggs/larvae in water column	free swimming; attach to shells, rocks, bottom debris by byssus -- up to about 10 mm	
	sexually mature in about 2 yr; form first discrete ring at 2-1/2 yr and spawn at end of that year	5

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*1. Lyles, 1969
2. Posgay, 1957
3. ICNAF, 1970
4. Dow, 1969
5. Merrill and Posgay, 1967.

Table 40. Details on the Yellowtail Flounder Fishery

Yellowtail flounder Limanda ferruginea

Characteristics		Data Source*
Commercial landings and economic importance	New England: 52,387,000 lb ($5,460,000)	1
	11,400 metric tons (5Y-990, 5Zw-9,735, 6A-675)	2
Geographical range	Gulf of St. Lawrence to Chesapeake Bay	3
Habitat preferences		
Water depth	6 to 40 fathoms	3
Temperature range	33 F to 54 F	3
Type of bottom	sand, sand-mud; shun rocky or mud bottoms	3
Food sources		
Fry	--	
Adults	small crustaceans, gastropods, bivalves, worms	3
Growth	average 5 in. first year	3
Mobility-migration		
Vertical	larvae take to bottom when about 14 mm long	3
Horizontal	Seasonal inshore-offshore	3,4
Behavioral characteristics	temperature tolerance 27°C	
Spawning		
Area	western and northwestern periphery of Gulf, 20-50 fathoms	3
Time of year	March-August	3
Position of eggs/larvae in water column	eggs pelagic	3

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*1. Lyles, 1969 2. ICNAF, 1970 5. deSylva, 1969
3. Bigelow and Schroeder, 1953. 4. Jones, 1968

Table 41. Details on the Ocean Pout Fishery

Ocean pout Macrozoarces americanus

Characteristics		Data Source*
Commercial landings and economic importance	New England: 1,000 lb 8719 metric tons (5Zw-8355, 6A-364)	1,2
Geographical range	New Jersey to Newfoundland, Gulf of St. Lawrence	3
Habitat preferences		
Water depth	bottom, 8-45 fathoms	3
Temperature range	32-62 F	3
Salinity range		
Type of bottom	hard; sandy mud, gravel	3
Food sources		
Adults	molluscs, crustaceans, echinoderms, invertebrates	3
Growth	1 yr: 4-5 in.	3
Mobility-migration		
Vertical	breed and live at bottom	3
Horizontal	autumnal shift to deeper water in northern regions	3
Behavioral characteristics	temperature tolerance 26.6-29°C	4
Spawning		
Area	no particular region -- rocky bottom	3
Time of year	Sept-Oct	3
Position of eggs/larvae in water column	eggs: 2-1/2 to 3 month incubation period; guarded by adults on bottom	3

*1. ICNAF, 1970
2. Lyles, 1969
3. Bigelow and Schroeder, 1953
4. deSylva, 1969

Table 42. Details on the Sculpin Fishery

Longhorn sculpin *Myoxocephalus octodecimspinosus*

Characteristics		Data Source*
Commercial landings and economic importance	6,687 metric tons (5Zw-6,556; 6A-121)	1
	no data on economic importance	2
Geographical range	Newfoundland to New Jersey	3
Habitat preferences		
Water depth	5-50 fathoms	3
Temperature range	32-66°F	3
Food sources		
Adults	omnivorous scavenger: shrimps, crabs, amphipods, hydroids, molluscs, squids, fish fry	3
Growth	1 yr: 2 to 2-1/2 in.	
Mobility-migration		
Horizontal	seasonal onshore-offshore moves; BIS: inshore Nov to Apr	3
Behavioral characteristics	temperature tolerance 28°C	4
Spawning		
Area	all along coast at all depths	3
Time of year	Nov to Jan	3
Position of eggs/larvae in water column	eggs sink -- adhesive demersal; adhesion disappears after incubation period	3

*1. ICNAF, 1969
2. Lyles, 1970
3. Bigelow and Schroeder, 1953
4. deSylva, 1969

Table 43. Details on the Winter Flounder Fishery

Winter flounder *Pseudopleuronectes americanus*

Characteristics		Data Source*
Commercial landings and economic importance	New England: 21,252,000 lb ($2,295,000)	1
	4,858 metric tons (5Y-900, 5Zw-3,886, 6A-72)	2
Geographical range	Newfoundland to Chesapeake Bay	3
Habitat preferences		
Water depth	bottom fish, 10-50 fathoms	
Temperature range	30-70°F	3
Salinity range	brackish	
Type of bottom	soft and hard	3
Food sources		
Fry	diatoms, small crustaceans	3
Adults	smaller invertebrates, fish fry, crustaceans	3
Growth:	2 yr: 5 to 7-1/2 in. 4 yr: 9 to 10 in.	
Mobility-migration		
Vertical	essentially stationary, keep near bottom	3
Horizontal	seasonal inshore-offshore below N.Y.; fry produced in estuaries work offshore with age	3
	migrate to ∼20 fathom line in summer, ∼15 mile seaward	4
Behavioral characteristics	temperature tolerance 27°C; found at upper and lower tide marks	
Spawning		
Area	New England	3
Time of year	Jan-May	
Position of eggs/larvae in water column	eggs sink to bottom	
Larvae development time	$2\frac{1}{2}$ to $3\frac{1}{2}$ months	

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*1. Lyles, 1969
2. ICNAF, 1970.
3. Bigelow and Schroeder, 1953.
4. Jones, 1968.

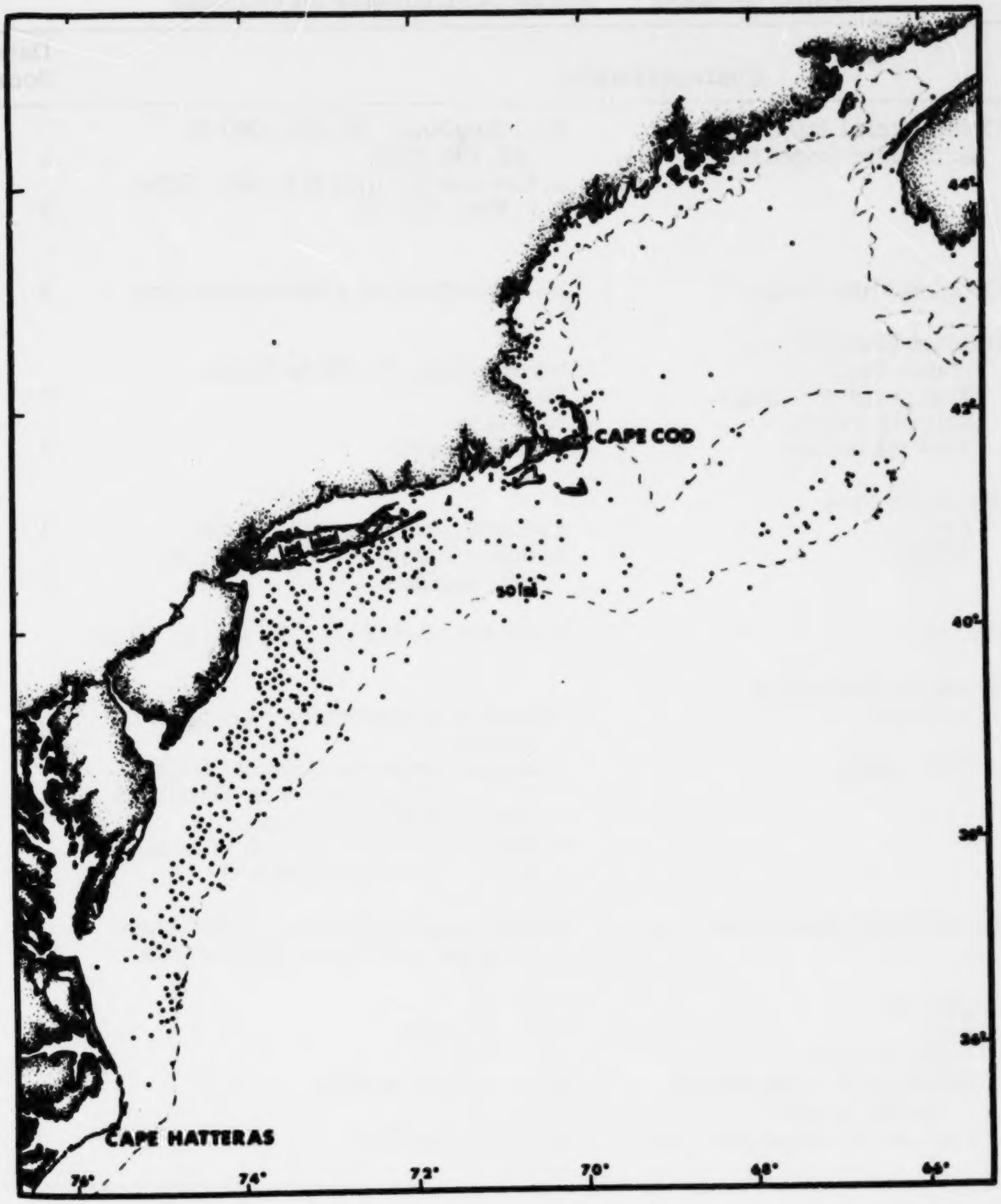
CAPE COD
50 fm.
CAPE HATTERAS
44°
42°
40°
38°
36°
76°
74°
72°
70°
68°
66°

Figure 51. Distribution of Ocean Quahogs in the Middle Atlantic Bight and the Gulf of Maine (from Merrill and Ropes, 1960)

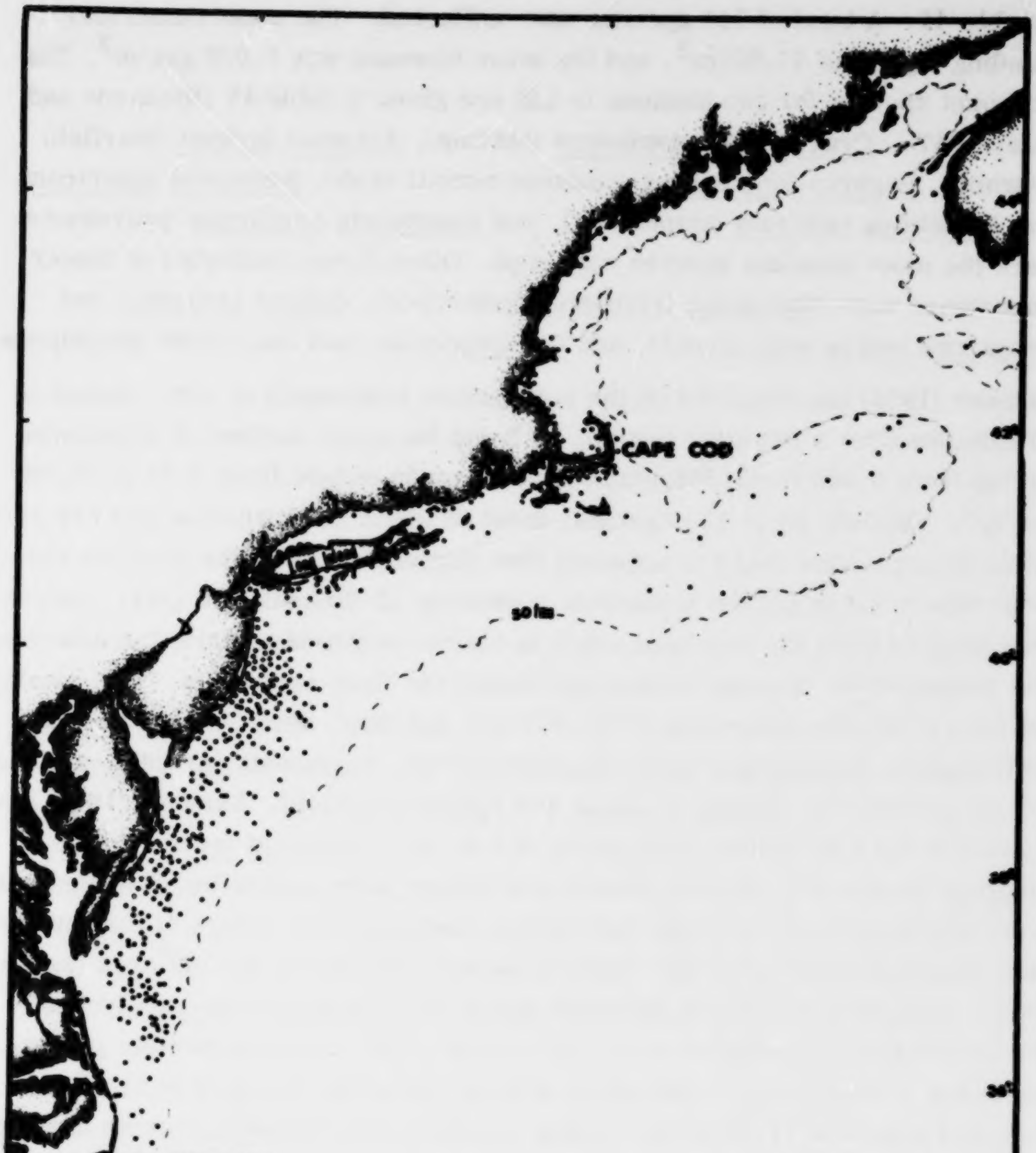
CAPE COD
50 fm
CAPE HATTERAS
76°
74°
72°
70°
68°
66°
42°
40°
38°
36°

Figure 52. Distribution of Surf Clams in the Middle Atlantic Bight and the Gulf of Maine (from Merrill and Ropes, 1960)

Benthic Organisms

The benthic epifauna population of LIS has been reported by Richards and Riley (1967). A list of invertebrates identified in their catches is shown in table 44. A total of 144 species was collected. The mean numerical standing crop was 77.00/m^2, and the mean biomass was 1.098 gm/m^2. The dominant species for two stations in LIS are given in table 45 (Richards and Riley 1967). *Cragon septemspinosus* (shrimp), *Asterias forbesi* (starfish) hydroids, *Pagurus longicarpus* (common hermit crab), *Neomysis americana* and *Ampelisca vadorum* (amphipods), and *Ampharete acutifrons* (polychaete) were the most abundant species collected. Other forms collected of lesser importance were *Nassarius trivittatus* (gastropod), *Cancer irroratus* and *Neopanope texana sayi* (crabs), and *Corophium* sp. and caprellids (amphipods).

Sanders (1956) has reported on the soft-bottom community of LIS. Based on 36 samples over a two-year period, he found the mean number of organisms varied from 5,563 to 43,398/station, and a mean weight from 4.54 to 36.38 gm/m^2. He lists some 135 species, most of which are identified and are similar to organisms found in adjacent New England areas. The greatest biomass was found in bottom sediments containing 13-25% silt and clay. Suspension feeders were the dominant types in coarse sediments, while the selective and nonselective deposit feeders dominated the finer sediments. The dominant forms found in sediments of 20-75% silt and clay, were *Nepthys incisa* (polychaete), *Cistenoides gouldii* (trumpet worm), amphipods (*Ampelisca*), and the lamellibranchs (*Yoldia limatula* and *Nucula proxima*). Sanders (1956) has described the soft-bottom community of LIS, as a *Nephthys incisa-Yoidia limatula* community, and it consists of a rather large population of organisms relatively small in size. The soft-bottom community structure of the Buzzards Bay, Massachusetts area was found to be very similar to the LIS area (Sanders 1960), consisting largely of *Nephthys incisa* and *Nucula proxima* (polychaete and lamellibranch, respectively). In a study of the deep-sea benthic population along a transect from Massachusetts to Bermuda, Sanders et al (1965) reported a general trend of decreasing numbers with increasing depth and distance from the continent (table 46). The single most abundant group was the Polychaeta. Polychaeta, together with the Crustacea, Pelecepoda and Sipunculoidea, comprise from 85-100% of the bottom fauna for most of the stations examined. Since the dominant juvenile demersal fish of the region (flounder)

Table 44. Listing of Benthic Invertebrates and Fishes Taken in Long Island Sound (from Richards and Riley, 1967)

Protozoa:
- Foraminifera, unidentified

Porifera:
- *Cliona* sp.
- *Microciona prolifera*

Bryozoa:
- *Alcyonidium polyoum*
- *Bowerbankia gracilis*
- *Membranopora* sp.

Coelenterata:
- *Thuiaria argentea*
- *Hydrallmania falcata*
- *Halecium halicinum*
- *Obelia gelatinosa*
- *Lafoea* sp.
- *Cerianthus* sp.
- *Astrangia danae*

Turbellaria:
- *Stylochus zebra*

Nemertina:
- *Cephalothrix linearis*
- *Cerebratulus luridus*
- *Amphiporus* sp.
- Unidentified (2)

Polychaeta:
- *Lepidonotus squamatus*
- Polynoidae, unidentified
- *Eteone lactea*
- *E. longa*
- *Phyllodoce fragilis*
- *P. groenlandica*

Polychaeta:
- *Phyllodoce* sp.
- *Paranaitis speciosa*
- *Eumida sanguinea*
- *Exogone dispar*
- *Autolytus cornutus*
- *Neanthes succinea*
- *Nereis pelagica*
- *Nereis* sp.
- *Nepthys incisa*
- *N. caeca*
- *N.* sp.
- *Glycera dibranchiata*
- *G.* americanus
- *G.* sp.
- *Diopatra cuprea*
- *Onuphis nebulosa*
- *Ninoe nigripes*
- *Arabella iricolor*
- *Polydora ciliata*
- *Streblospio benedicti*
- Spionidae, unidentified (2)
- *Flabelligera affinis*
- *Travisia carnea*
- Capitallidae, unidentified
- Maldanid
- *Maldane* sp.
- *Cistenides gouldii*
- *Melinna cristata*
- *Ampharete acutifrons*
- *Amage auricula*
- *Amphitrite* sp.
- Lysilla alba

Table 44 (Cont'd)

Polychaeta:

- *Polycirrus eximus*
- *Potamilla neglecta*
- *Sabella crassicornis*
- *S. microphthalma*
- *Eupomatus dianthus*
- Unidentified

Crustacea:

- *Cytheridea americana*
- *Sarsiella zostericola*
- *Centropages* sp.
- *Temora longicornis*
- *Eurytemora* sp.
- *Labidocera aestiva*
- *Acartia clausi*
- *Balanus balanoides*
- *Neomysis americana*
- *Heteromysis formosa*
- *Diastylis polita*
- *Oxyurostylis smithi*
- *Edotea montosa*
- Bopyrid isopod
- *Anonyx* n. sp.
- *Orchomenella minuta*
- *Ampelisca vadorum*
- *Ampelisca abdita*
- *Stenothoe cypris*
- *Calliopius laeviusculus*
- *Carinogammarus mucronatus*
- *Gammarus annulatus*
- *Melita nitida*
- *Leptocheirus pinguis*

Crustacea:

- *Podoceropsis nitida*
- *Erichthonius brasiliensis*
- *Unciola irrorata*
- *Corophium* sp.
- *Caprella linearis*
- *Paracaprella tenuis*
- *Deutella incerta*
- Caprellid
- *Crangon septemspinosa*
- Shrimp, unidentified
- *Pagurus longicarpus*
- *P. pollicaris*
- *Pinnixia sayana*
- *Ovalipes o. ocellatus*
- *Callinectes sapidus*
- *Cancer irroratus*
- *Panopeus herbstii*
- *Neopanope texana sayi*
- *Pelia mutica*
- *Libinia emarginata*

Mollusca

- *Nucula proxima*
- *Yoldia limatula*
- *Anadora transversa*
- *Anomia simplex*
- *Pandora gouldiana*
- *Lyonsia hyalina*
- *Cerastoderma pinnulatum*
- *Gemma gemma*
- *Macoma tenta*
- *Ensis directus*

Table 44 (Cont'd)

Mollusca:

- *Mulinia lateralis*
- *Saxicava arctica*
- *Polinices duplicatus*
- *Crepidula fornicata*
- *Crepidula plana*
- Limpet, unidentified
- *Cerithiopsis subulata*
- *Siela adamsii*
- *Bittium alternatum*
- *Eupleura caudata*
- *Mitrella lunata*
- *Nassarius trivittatus*
- *Retusca canaliculata*
- *Cylichna alba*
- *Aeolidia papillosa*
- Snail, unidentified

Chaetognatha:

- *Sagitta* sp.

Echinodermata:

- *Asterias forbesi*

Pisces:

- *Anchoa mitchilli*
- *Auguilla rostrata*
- *Syngnathus fuccus*
- *Ammodytes hexapterus*
- *Prionotus carolinus*
- *Myoxocephalus aeneus*
- *Scopthalmus aquosus*
- *Pseudopleuronectes americanus*

Table 45. Abundance of Epifaunal Species (from Richards and Riley, 1967)

Species	Mean Values	
	Number/m^3	Dry Weight/m^3
Station 1:		
Asteria forbesi	2.25(4)*	0.770(1)*
Crangon septemspinosa	6.62(3)	0.135(2)
Cancer irroratus	0.06(11)	0.116(3)
Libinia emarginata	0.01(13)	0.072(4)
Hydroids	-	0.064(5)
Pagurus longicarpus	0.93(7)	0.047(6)
P. pollicaris	0.04(12)	0.045(7)
Nassarius trivittatus	0.94(6)	0.031(8)

Table 45 (Continued)

Species	Mean Values	
	Number/m^3	Dry Weight/m^3
Neopanope texana sayi	0.60(8)	0.018(9)
Neomysis americana	0.31(2)	0.006(10)
Crepidula plana	0.49(9)	0.003(11)
Lepidonotus squamatus	0.046(10)	0.002(12)
Caprellids	4.19(1)	0.001(13)
Unciola irrorata	1.14(5)	+ (14)
Station 3A:		
Asterias forbesi	0.24(5)	0.124(1)
Crangon septemspinosa	0.44(2)	0.006(2)
Cancer irroratus	+ (11)	+ (8)
Libinia emarginata	0	0
Hydroids	-	0.002(5)
Pagurus longicarpus	0.01(7)	0.001(6)
P. pollicaris	0	0
Nassarius trivittatus	0.34(3)	0.006(3)
Neopanope texana sayi	0.01(9)	+ (7)
Neomysis americana	2.57(1)	0.002(4)
Crepidula plana	0.04(6)	+ (10)
Lepidonotus squamatus	0.01(10)	+ (11)
Caprellids	0.29(4)	+ (9)
Unciola irrorata	0.01(8)	+ (12)

Table 46. Abundance of Benthic Animals for Transect Stations from Massachusetts to Bermuda (from Sanders et al, 1965)

Station	Depth (m)	Latitude	Longitude	Number of Animals in Sample	Number of Animals/m^2
55	75	40° 27.2'N	70° 47. 5'W	3,791	13,073
C#1	97	40° 20.5'N	70° 47'W	3,082	5,314
Sl.2	200	40° 01.8'	70° 42'	6,455	12,910
Sl.3	300	39° 58.4'	70° 40.3'	11,907	21,263
Sl.4	400	39° 56.5'	70° 39.9'	4,439	6,081
D#1	487	39° 54.5'	70° 35'	5,115	8,669
E#3	823	39° 50.5'	70°-35'	3,008	2,979
F#1	1500	39° 47'	70° 45'	997	1,719
G#1	2086	39° 42'	70° 39'	1,120	2,154
GH#1	2500	39° 25.5'	70° 35'	365	521
GH#4	2469	39° 29'	70° 34'	299	467
HH#3	2870	38° 47'	70° 08'	636	748
II#1	3742	37° 59'	69° 32'	--*	--*
II#2	3752	38° 05'	69° 36'	391	1,003
JJ#1	4436	37° 27'	68° 41'	264	264
JJ#3	4540	37° 13.1'	68° 39.6'	101	158
KK#1	4850	36° 23.5'	68° 04.5'	113	92
LL#1	4977	35° 35'	67° 25'	67	55
MM#1	5001	34° 45'	66° 30'	27	33
NN#1	4950	33° 56.5'	65° 50.7'	51	38
OO#2	4667	33° 07'	65° 02.2'	58	126
Ber. 7	2500	32° 15'	64° 32.6'	91	120
Ber. 5	2000	32° 11.4'	64° 41.6'	89	189
Ber. 4	1700	32° 17'	64° 35'	217	271
Ber. 3	1700	32° 16.6'	64° 36'3'	126	274
Ber. 2	1700	32° 16.6'	64° 36 3'	189	215
Ber. 6	1500	32° 14.3'	64° 42'	208	178
Ber. 8	1000	32° 21.3'	64° 33'	326	729
Ber. 1	1000	32° 16.5'	64° 42.5'	243	528

*Sample excluded from quantitative analysis because of small size prefers species of *Neomysis*, *Cragon*, and copepods in its diet, competition for bottom forms as food is apparently minimal due to the abundance of copepods and amphipods in the area (Richards and Riley, 1967).

The food habits of juvenile and larval winter flounder have been studied by Pearcy (1962). Larval forms feed primarily on nauplii, polychaetes, invertebrate eggs, and small protozoa. Juvenile fish feed primarily on calanoid copepods. The young flounder feed primarily on amphipods and polychaetes. The two most important species preyed upon are *Ampelisca* (amphipod) and *Neanthes* (polychaete). Pearcy (1962) indicates that the flounder feeds primarily at night and is euryphagous, having identified 77 food organisms from 7 different phyla in the stomach analyses of juvenile flounder. The important food species for juvenile fish of LIS found by Richards (1963b and 1963c) were:

Hydroids (unidentified)
Neanthes succinia
Ampharete acutifrons
Pseudodeaplomus coronatus
Temora longicornis
Acartia spp.
Neomysis americana
Leptocheirus pinquis
Ampelisca spp.
Caprella spp.
Cragon septemspinosus
B. balanoides larvae
Nephthys incisa
Labidocera aestiva

Crustaceans were by far the most important food organisms; and of these *Neomysis americana* was preferred by the greater number of fish. Sanders (1952), studying the food and feeding habits of the herring in BIS, reported that the copepod *Pseudocalanus minutus* was the most abundant form found in stomach analysis of herring. Sanders (1952) also lists *Centropages typicus*, *Temora longicornus*, *B. balanoides* larvae, *Oithona similis*, *Acartia tonsa*, and *Sagitta elegans* as important planktonic food forms, and *Cragon septemspinosus* (shrimp), *Mechtheimysis stenotepsis* (mysid), *Diastyles* spp. (cumacid), *Dulichia monocantha* and *Monoculodes edwardsi* (amphipods), and *Nereis* (polychaete) as important benthic food forms.

Fouling

Fouling of engineered structures and equipment can be expected generally at any marine site. Unless careful considerations and precautions are taken, accumulations and growth on submerged objects can be enormous. Characteristics and results of fouling are summarized in table 47 (A. D. Little, 1962).

A list of the common organisms associated with the fouling community is given in table 48. Of the 17 recognized animal phyla, only four are not generally associated with the fouling community: Ctenophora, Chaetognatha, Nematoda, and Phoronidea (Redfield and Deevey, 1952a). The predominant foulers are generally sessile organisms and include barnacles, bryozoans, hydroids, calcareous tubeworms, tunicates, mussels, jingle shells, oysters amphipod tubes, and seaweeds. Because of the host of biological, physical, and chemical parameters affecting fouling, the composition of the fouling community is highly variable. The fouling organisms and periods of attachment at two sites (Woods Hole, Mass. and in the approaches to Chesapeake Bay, Md.) are shown in figures 53 and 54. Fouling is largely seasonal, occurring predominately in the warm months of spring, summer and early fall. The colder months of December, January, and February are months of least fouling activity. Fouling is maximum near shore and as the distance from shore is increased less fouling is encountered. Fouling in relation to distance from shore, for a location in the approaches to Chesapeake Bay, is presented in table 49 (Hutchins, 1952). Fouling at 30 miles from shore was moderate; at 60 miles from shore fouling was least. Note that the predominant fouling forms at depths greater than 30 ft were hydroids, goose barnacles, and sponges. Intensive fouling activity does not occur at depths below 150 ft. The fouling intensity at various depths in the New England area water is given in figure 55 (Hutchins, 1952). Fouling intensity was greatest at depths less than 100 ft and, at best, was about 5 lb/ft^2. At the Narragansett Bay site (VI) fouling intensity was more severe, ranging from 15-30 lb/ft^2. At depths greater than 150 ft, fouling intensity was in every case less than 1 lb/ft^2. The 12-month cumulative fouling obtained for curved stainless steel test panels, immersed at two sites (38 ft and 68 ft depths) in the approaches to Chesapeake Bay, was from 31 to 38 oz/ft^2 (Daugherty, 1961). The intensity of fouling in general offshore New England waters can be expected to range from approximately 2-30 lb/ft^2.

Table 47. Characteristics and Results of Marine Fouling (from A. D. Little, 1962)

Factors Affecting the Type and Rate of Marine Fouling

1. Temperature
2. Geographical location
3. Depth
4. Land masses
5. Light
6. Oxygen content
7. Currents
8. Salinity
9. Organic nutrients

Principal Types of Marine Fouling Processes

1. Erosion and solution of surfaces by organisms and their metabolic end-products.
2. Silting, deposition of mud, debris and organisms.
3. Accumulation of organisms and deposition of materials by them.

Results of Fouling on Submerged Objects

1. Moving parts may be rendered inoperable.
2. Inlets and outlets may be clogged.
3. Overall buoyancy of the device may be altered.
4. Deposits may alter transmitter and receiver characteristics.
5. Resistance to fluid flow changes.
6. Heat transfer characteristics may be altered.
7. Chemical composition of surface may change, thus changing redox-potentials.
8. Corrosion rates may be altered.

Table 48. Common Fouling Organisms (adopted from Ayers and Turner, 1952)

I. Plants

- a. Diatoms -- bacteria (numerous types)
- b. Chlorophyta (green algae)
    - Ulva
    - Enteromorpha
    - Cladophora
    - Codium
- c. Phaeophyta (brown algae)
    - Ectocarpus
    - Fucus
    - Ascophylum
    - Laminaria
- d. Rhodophyta (red algae)
    - Ceramium
    - Porphyra
    - Polysiphonia
    - Chondrus

II. Animals

- a. Protozoa (numerous types)
- b. Porifera (sponges)
- c. Coelenterata (anemones, hydroids, corals)
    - Metridium
    - Plumularia
    - Eudendrium
    - Obelia
- d. Bryozoa (encrusting and/or tufted-like)
    - Membranipora
    - Crisia
    - Bugula
- e. Annelida
    - Nereis
    - Hydroides
    - Spirorbis
- f. Arthropoda (crustaceans, cirripedians)
    - Amphipods
    - Limnoria
    - Barnacles
- g. Mollusca
    - Anomia
    - Mytilus
    - Pododesmus
    - Hiatella
    - Bankia
    - Xylophaga
- h. Chordata (tunicates)
    - Ciona
    - Styela
    - Ascidia
    - Botryllus

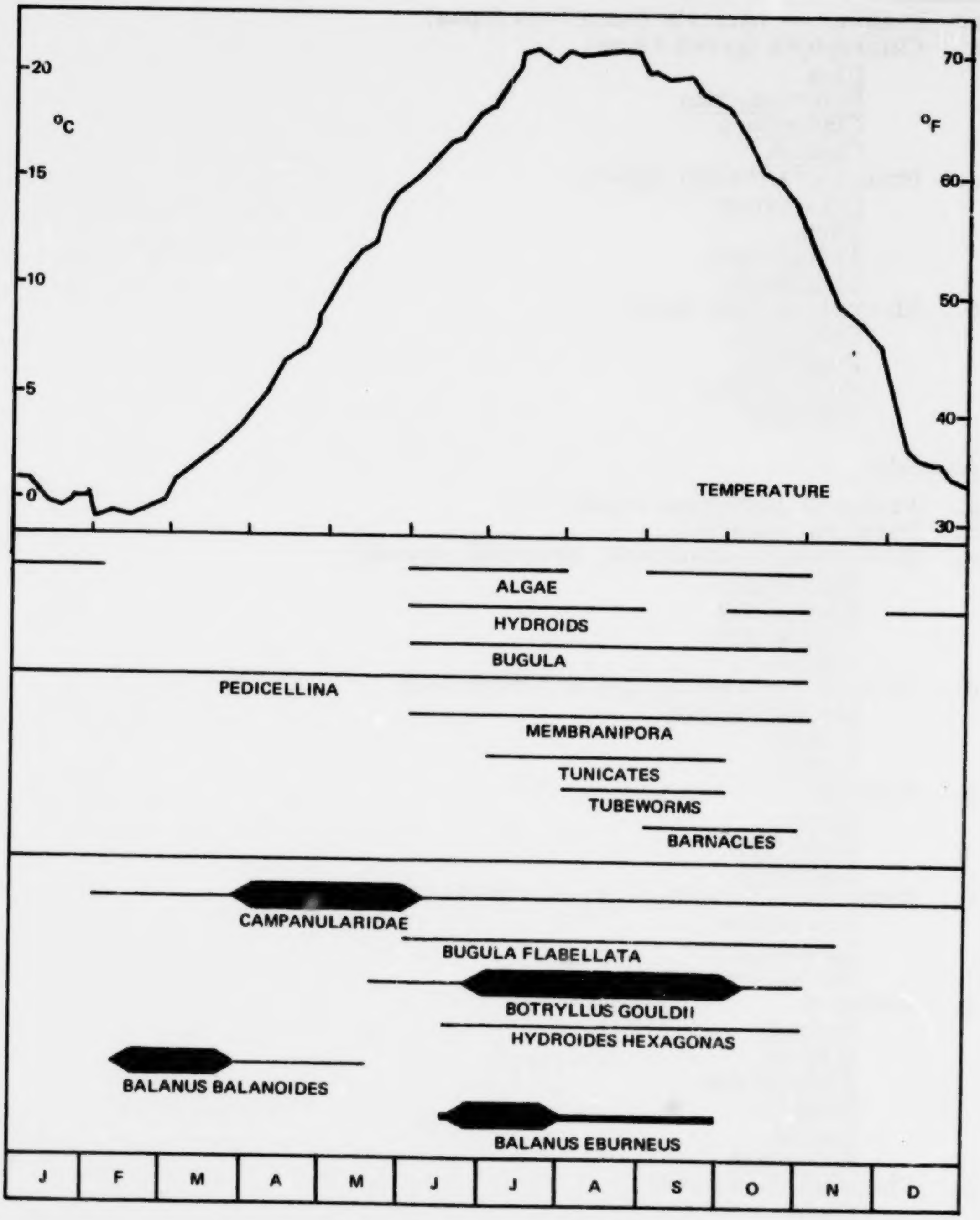

Figure 53. Fouling at Woods Hole Site Showing Periods of Attachment of Fouling Organisms (from Redfield and Deevy, 1952b)

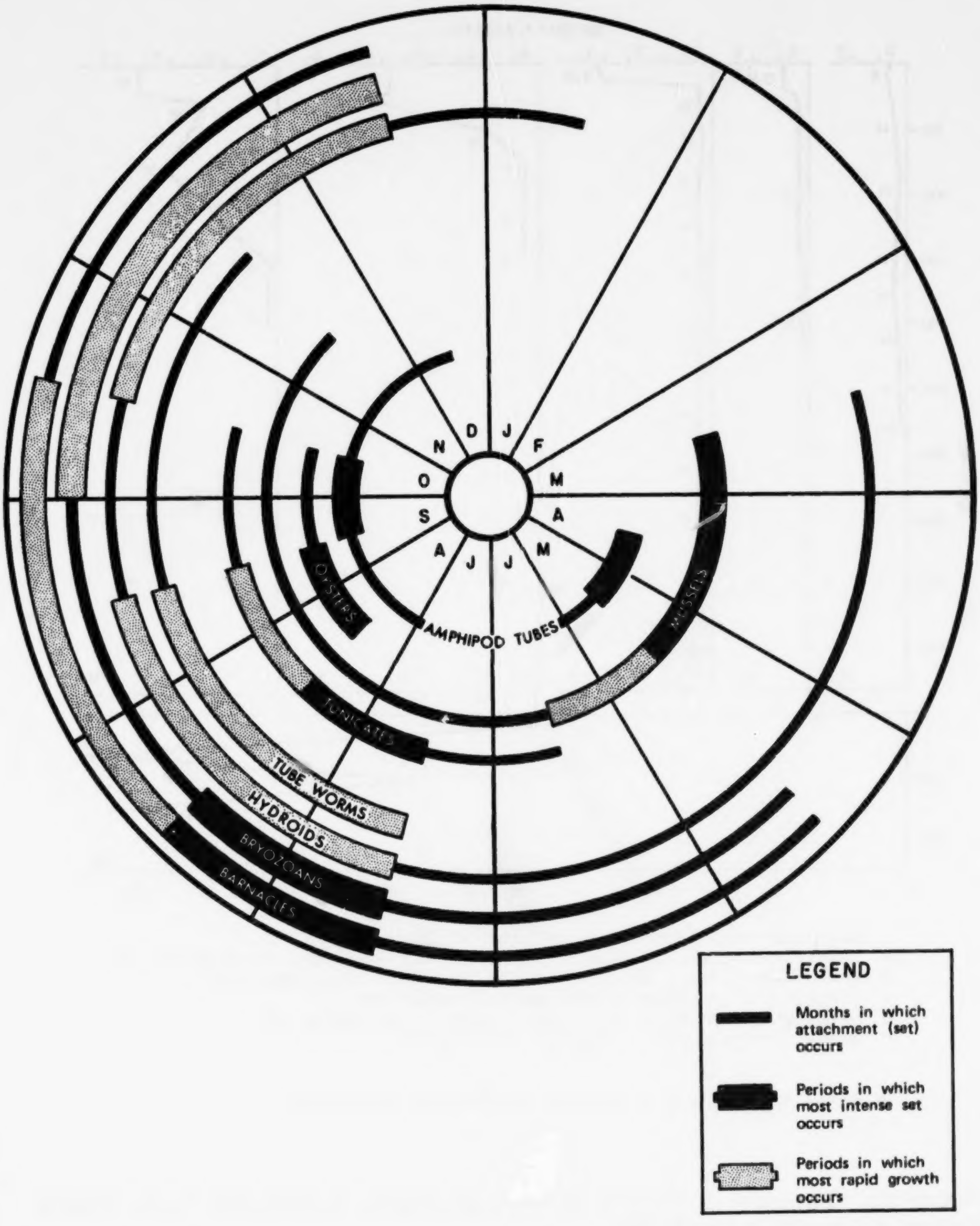

Figure 54. Fouling at Chesapeake Bay Site -- Periods of Attachment, of Maximum Attachment, and of Most Rapid Growth (from Daugherty, 1961)

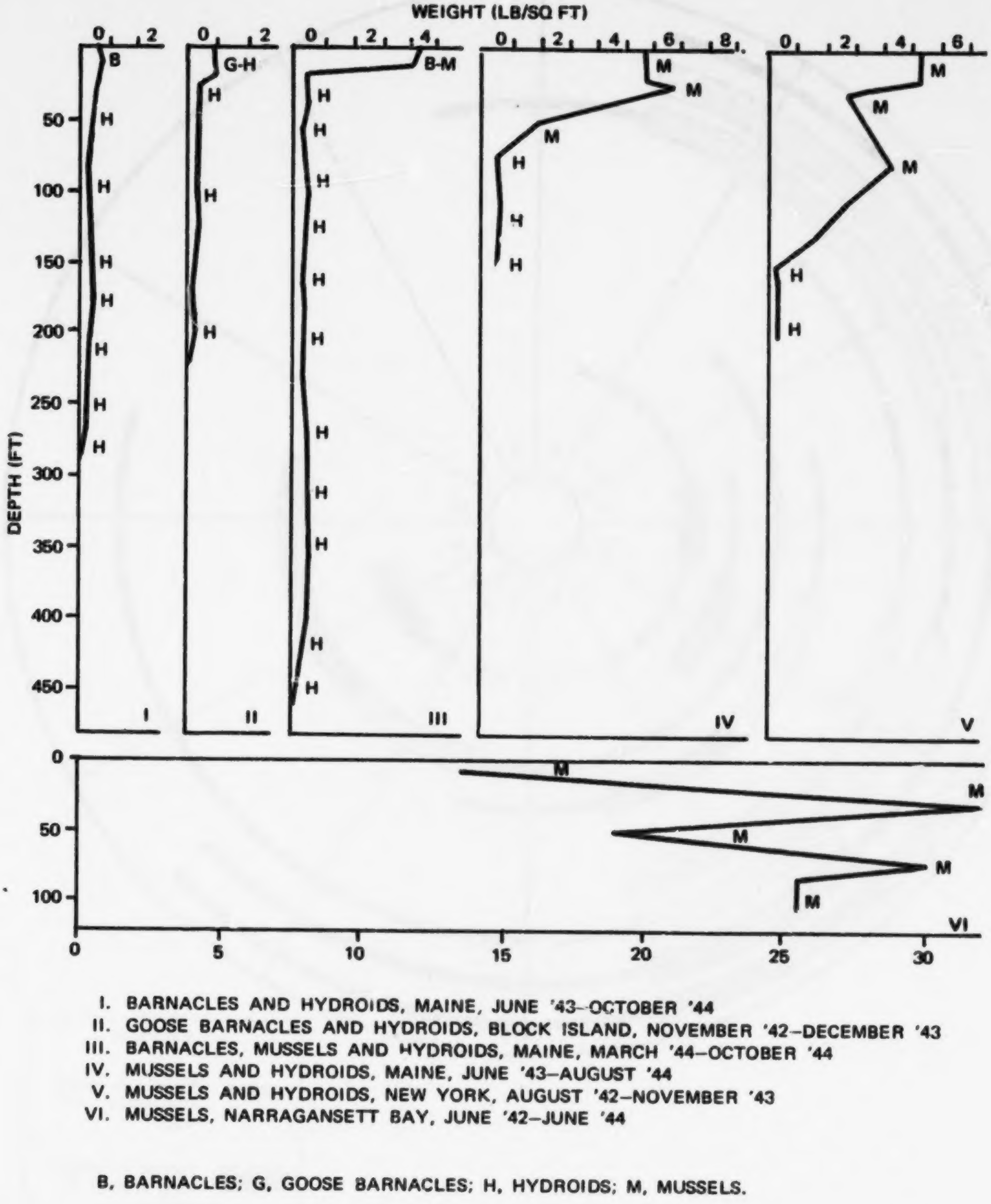

Figure 55. Intensity of Fouling at Various Depths on Selected Buoys Where Fouling Extended to the Bottom

Table 49. Fouling in Relation to Distance from Shore (from Hutchins, 1952)

Distance from Shore (mi)	Water Depth (ft)	Degree of Fouling	Comments
20	70	severe	heavy accumulations; large number of mussels.
30	90	moderate (patchy)	heavy accumulations of mussels to about 30-ft depth; below this, hydroids and sponges -- but less severe than near shore
60	186	moderate to poor	few mussels; largely goose barnacles, algae, hydroids, and sponges.

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Section 4

SITE DESCRIPTION FOR WATERS OFF SOUTHEASTERN FLORIDA

PHYSICAL DESCRIPTION (MIAMI AREA)

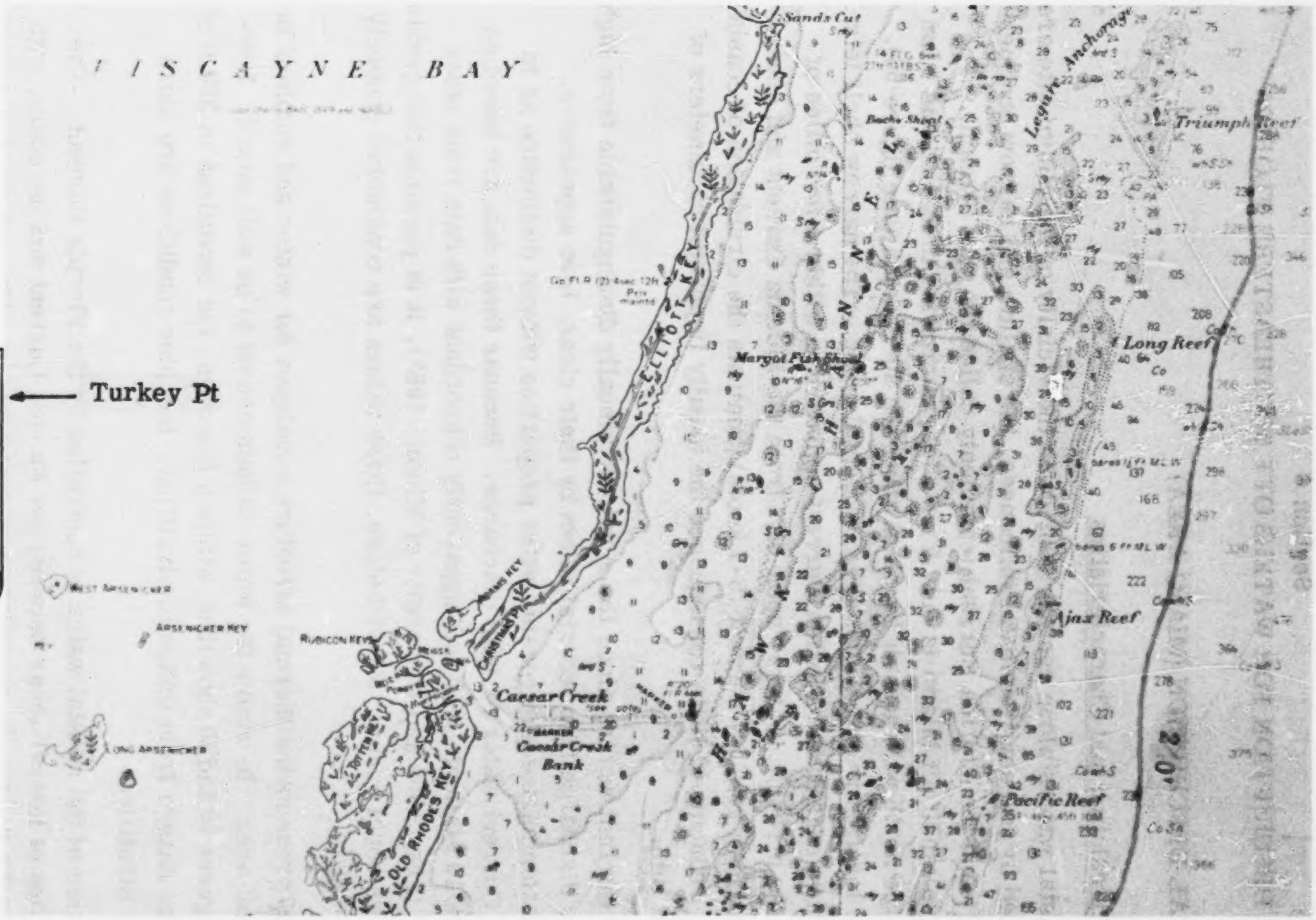
Water Circulation and Characteristics

The coastal waters along eastern Florida in the vicinity of the Miami site are dominated by two environmental influences, the shallow and narrow continental shelf, and the Florida Current (commonly called the Gulf Stream). The continental shelf off Miami is only 5 nm wide, narrowing to as little as 1 nm wide to the north with a shelf break at about the 90-ft depth (see figure 56). The site location is actually on the continental slope. The narrow shelf lets the western edge of the Florida Current approach to within a few miles of shore. As a result, waters "spun-off" from the Florida Current and shear from this high velocity current (5-7 knots) dominate the circulation of coastal waters, reducing to little consequence the usually important parameters of wind and tide.

Florida Current waters along the coast are visually distinguishable from high turbidity discharge from coastal inlets by their clear, blue appearance. Table 50 summarizes the coastal water properties without distinction as to Florida Current water or inlet discharge. Because these data are based on less than 10 stations, although apparently concordant with data from other sources (Lee, 1969 and University of Miami, 1963), it is possible that greater variations could occur. Nevertheless, these values are considered properly representative.

Figure 57 presents the thermal structure envelopes for winter and summer in the Miami area. In winter the water column seems to be well mixed. However, figures 58 and 59 show that, within a few days, the conditions in 250 ft of water can change from mixed to stratified. Summer conditions are more strongly stratified.

Circulation of the coastal water is controlled by the Florida Current. The area is one of lateral shear between the Florida Current and the coast, with current velocity decreasing as the water shoals and eddies of Florida Current water are spun off into this transition zone. Currents observed from a point


BISCAYNE BAY
Turkey Pt
Sands Cut
ELLIOTT KEY
Legare Anchorage
Triumph Reef
Bache Shoal
Long Reef
Margot Fish Shoal
HAWK CHANNEL
Ajax Reef
Pacific Reef
Caesar Creek
Caesar Creek Bank
RUBICON KEYS
OLD RHODES KEY
TOTTEN KEY
WEST ARSENICKER
ARSENICKER KEY
LONG ARSENICKER
20'

Reproduced from best available copy.

Figure 56. Soundings (ft) off Turkey Point, Typical of Southeastern Florida Coast (from Coast and Geodetic Survey Chart 1249)

Table 50. Temperature, Salinity and Density Data* for the Miami Site

Depth (M)	Density (σ_t)			Temperature (^{o}C)			Salinity ($^{o}/oo$)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
				Winter					
0	24.39	25.38	23.45	24.23	26.90	21.71	36.06	36.40	35.22
10	24.51	25.48	23.53	24.05	26.65	21.12	36.16	36.32	35.90
20	24.55	25.59	23.59	23.92	26.46	20.52	36.16	36.26	35.90
30	24.63	25.72	23.62	23.62	26.35	19.92	36.16	36.34	35.90
50	24.78	26.02	23.61	23.20	26.40	18.69	36.20	36.47	35.90
75	25.37	26.43	24.43	21.76	25.75	17.09	36.21	36.26	36.18
100	26.01	26.87	25.03	18.15	22.55	14.14	35.90	36.25	35.61
125	26.63	27.11	26.27	15.15	17.70	11.66	35.67	36.19	35.57
				Summer					
0	22.85	23.24	22.31	28.94	29.70	28.19	36.01	36.21	35.57
10	22.95	23.51	22.43	28.69	29.63	27.40	36.03	36.20	35.69
20	23.09	23.85	22.56	28.43	29.65	26.31	36.08	36.27	35.81
30	23.37	24.24	22.68	27.75	29.30	24.98	36.14	36.52	35.93
50	24.39	25.65	23.06	24.90	28.85	19.60	36.20	36.43	36.00
75	25.60	26.89	24.42	20.13	24.89	12.41	36.11	36.36	35.46
100	26.25	27.03	25.27	17.22	22.86	12.63	36.09	36.55	35.16
125	26.64	27.29	25.89	14.72	20.12	10.09	35.80	36.50	34.97

*Temperature is given in degrees Celsius, salinity in parts per thousand ($^{o}/oo$), and density in sigma-t units (where, e.g., 24.39 represents a specific gravity of 1.02439).

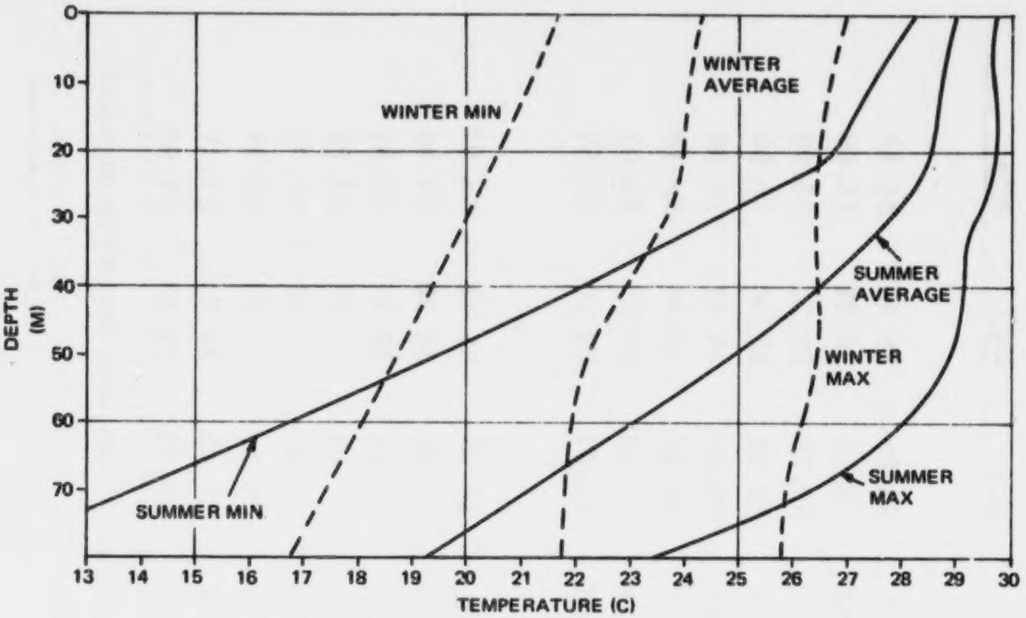


Figure 57. Thermal Stratification of Miami Site

in the coastal area will show extreme variability in velocity and direction, currents of up to 2 knots being observed heading south, opposite to the Florida Current direction. Lee (1969) has made the only comprehensive study of coastal circulation (along the eastern Florida coast 30 nm north of the Miami area). It is reasonable to assume that Lee-data will generally describe the type of circulation in the site area off Miami.

Figure 60 is an approximation of the coastal circulation as constructed by Lee. The northbound Florida Current velocity decreases as the water shoals, with maximum normal velocities of 2.0 knots close to shore. However, vagaries in the Florida Current could result in 4.0-knot velocities at the site location (Lee, telephone communication, 1970). The meandering of the western edge of the Florida Current causes the formation of eddies of fluctuating velocity and direction, as shown in the center of figure 60. This reconstruction depicts an average eddy containing a substantial amount of southbound as well as eastbound and westbound water. The eddies measure roughly 6-8 nm from east to west and 10-12 nm from north to south; they have cyclonic (counterclockwise) circulation. The typical eddy migrates northward at an average speed of 0.6 knots, giving a 20.5-hr period of passage. An estimated 4 eddies a

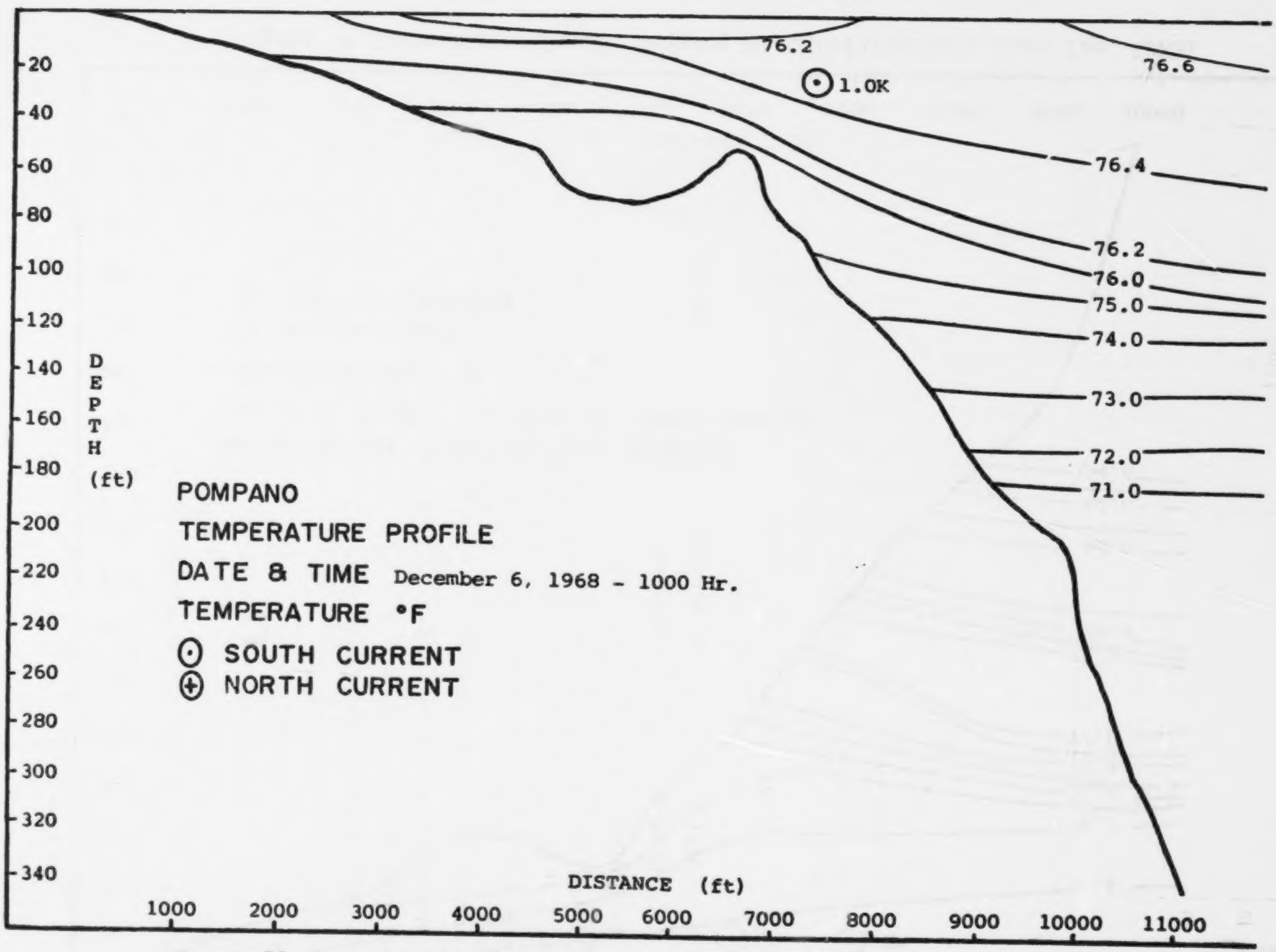


Figure 58. Temperature Profile Showing Mixed Condition (from Lee, 1969)

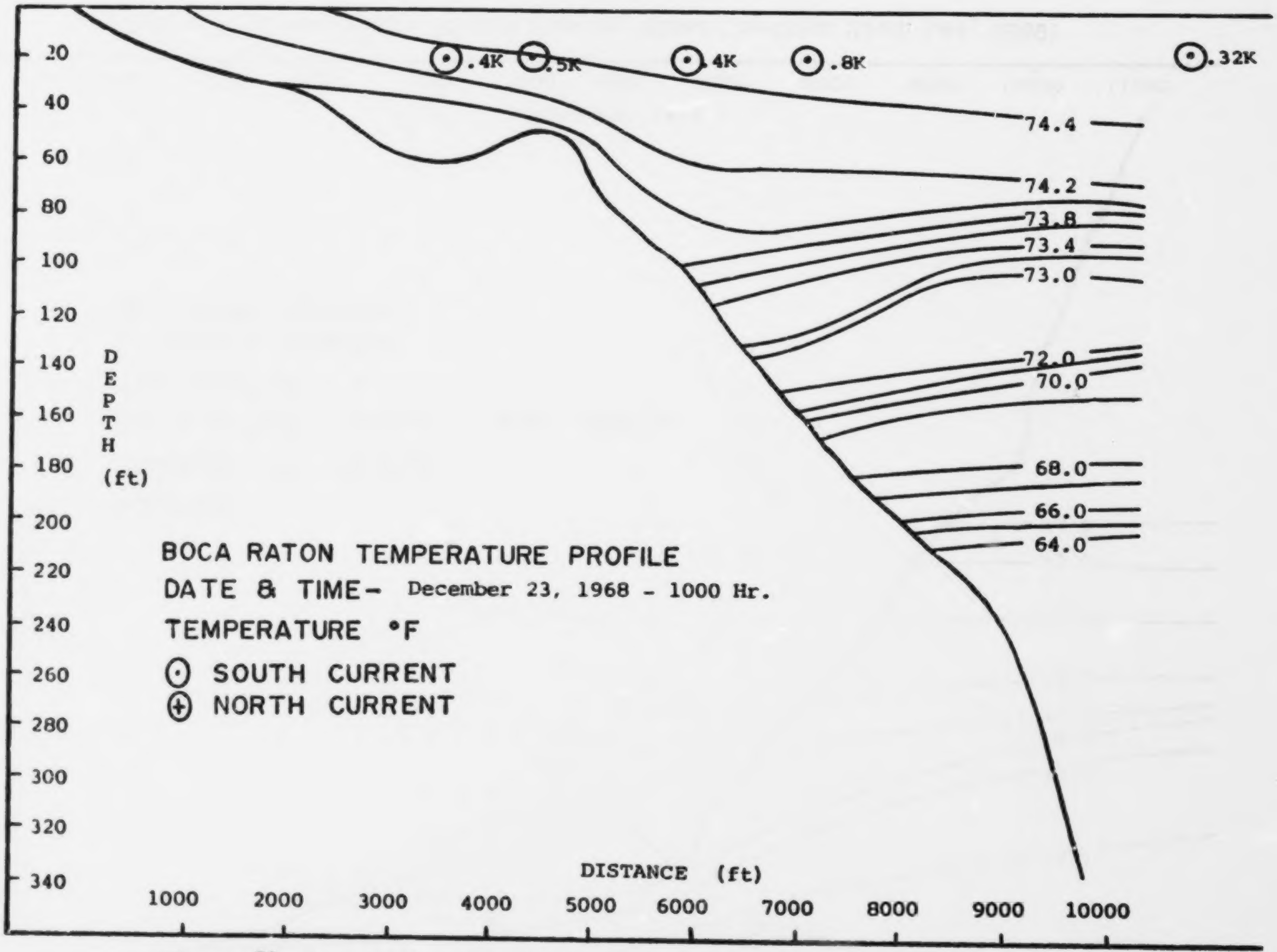


Figure 59. Temperature Profile Showing Stratified Condition (from Lee, 1969)

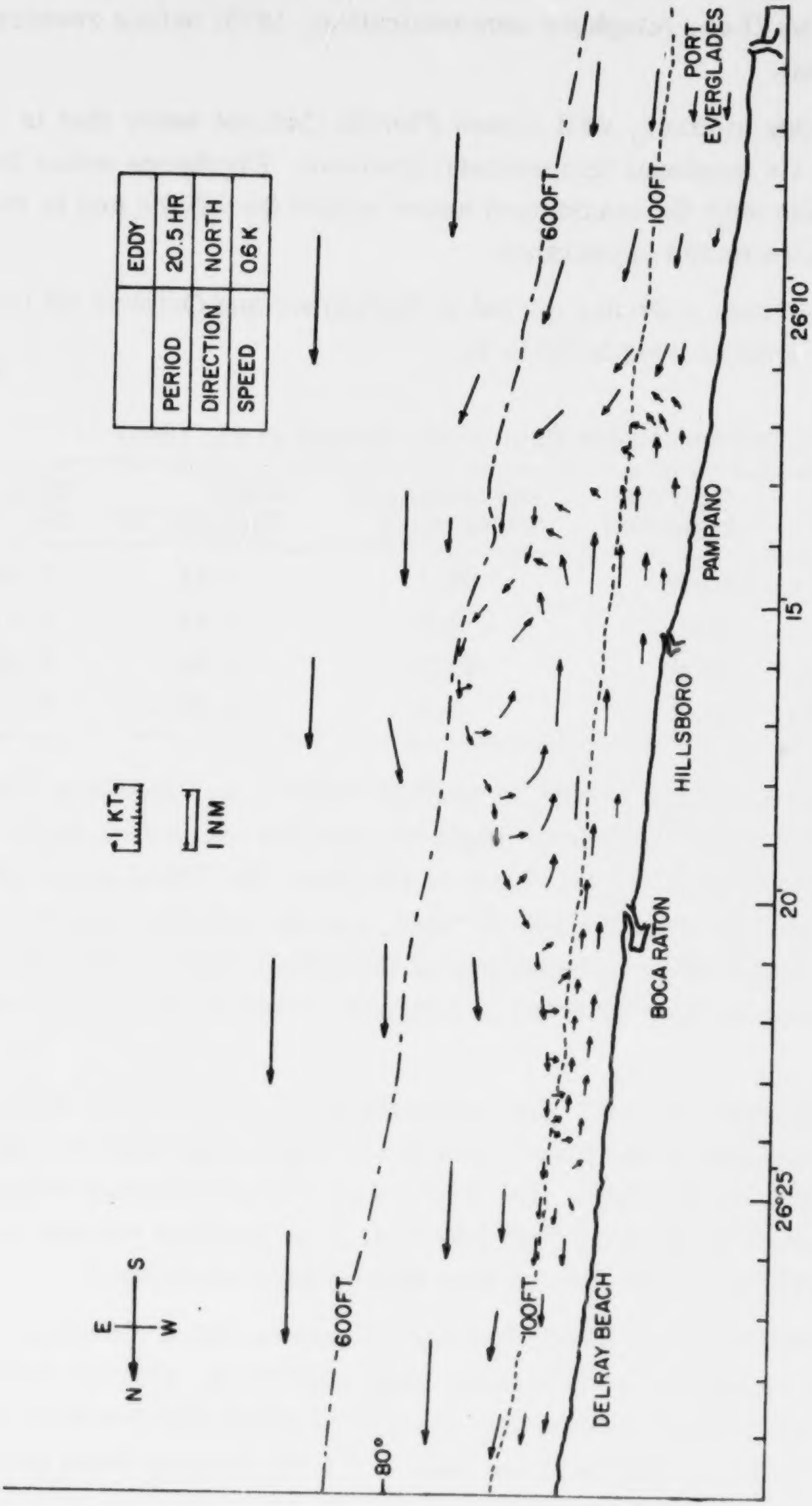

EDDY
PERIOD 20.5 HR
DIRECTION NORTH
SPEED 0.6K
1 KT
1 NM
N
E
S
W
600FT
100FT
PORT EVERGLADES
PAMPANO
HILLSBORO
BOCA RATON
DELRAY BEACH
26°10'
15'
20'
26°25'
80°

Figure 60. Circulation Pattern of Florida Current Waters

week can pass through an area, and the residence time of an eddy on the shelf is estimated at 1 wk (Lee, telephone communication, 1970) before reentering the Florida Current.

The water in an eddy is clear, well-mixed Florida Current water that is nearly uniform in its sectional temperature gradient. Discharge water from coastal inlets mixes with the northbound water behind the eddies and is recognized by its more turbid appearance.

Currents measured over a 29-day period in September and October off the Florida coast are summarized in table 51.

Table 51. Current Meter Data (from Stewart et al, 1969)

Quadrant	Current Direction	Percentage of Occurrence	Mean Velocity (kt)	Mean Std. Dev.
316-45° (NW-NE)	north	59.1	0.44	0.22
46-135° (NE-SE)	east	5.9	0.34	0.12
136-225° (SE-SW)	south	27.9	0.46	0.20
226-315° (SW-NW)	west	7.0	0.23	0.12

Measurements were made in relatively shallow water (i.e., less than 100-ft depth), and slightly higher velocities might be expected at a 250-ft depth. However, because of steep bottom slopes in the area, the 250-ft depth will only be a short distance from the 100-ft depth, and the current velocities should not differ materially. Comparison of the data in table 2 with other measurements taken by Lee indicates no seasonal trends in the current patterns.

From all of Lee's measurements, the northerly (270°-90°) current direction was observed 73 percent of the time. Southbound water may persist from a few hours to as long as 60 hours. The westbound current carrying offshore water in to the coast, lasts more than 2 hr and, at an average velocity of 0.2 kt, the water parcel would be carried only about 3000 ft shoreward.

Of the current velocities measured, Lee has calculated that a maximum of 0.21 kt could be caused by the tide under ideal conditions, although normally the tidal component will be considerably less. The flood-ebb direction is north and south since the area is at the node of a tidal standing wave going from the Atlantic Ocean into the Gulf of Mexico. The tidal effect along the coast is most noticeable when the axis of the Florida Current is farthest offshore.

Bottom Characteristics

The continental shelf in the Miami area is a reef tract, and is shallow and narrow, the shelf break occurring at about the 90-ft depth, within 5 nm of shore. Consequently, the Miami plant site actually lies on the continental slope, the slope gradient averaging 3 to 4°. Figure 61 depicts the transition from an irregular (due to reefs) shallow shelf with thin sediment cover, to the steeply dipping, smooth continental slope with a thick accumulation of sediment. These sediments are composed of reef detritus which has been washed off the shelf and shore locally. Samples of these sediments have not been located in the literature, but it is most probable that they are composed of carbonate silts and clay (Uchupi, 1963). The finer sediments predominate on the continental slopes (Shepard, 1963). Because of the declivity of the bottom off Miami (3-4°), and since sediment accumulation may be rapid, subaqueous sediment sliding could be an important factor in site determination. There is at present no known documentation of sediment instability on the slope off Miami, but the possibility must be considered.

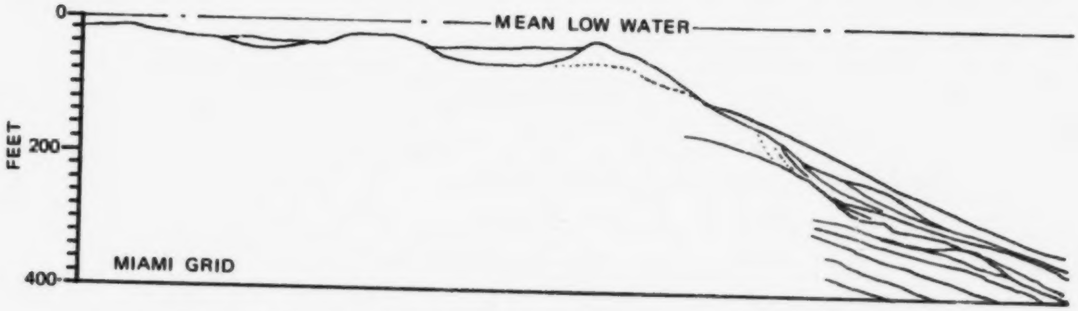


Figure 61. Shelf Profile Off Southeastern Florida

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BIOLOGICAL DESCRIPTION (MIAMI AREA)

Ecology

The ecology of offshore waters in the Miami region of Florida has been studied in very broad outline, mainly with regard to the fisheries and plankton. The Bureau of Commercial Fisheries Laboratory at Woods Hole, with other government agencies, is making a benthic survey along the Atlantic coast, which includes this region. Visual observations of the bottom and life in a transect off West Palm Beach are presented by Emery et al (1970).

The unique environmental features of the Miami region are the presence of tropical blue water within a few miles of shore with relatively uniform temperature year-round, a euphotic zone of some 100 meters, and the presence of coral reefs, especially south of Miami. Biologically, these waters are generally characterized by (1) the great variety of plant and animal species present, each constituting only a small percentage of the total biomass, (2) low standing crops of plankton and the absence of marked seasonal pulses in abundance, and (3) a high proportion of small phytoplankton and zooplankton species with low regeneration times, presumably resulting in rapid cycling of available nutrients.

The energy to drive the offshore biological system is believed to be produced offshore by the photosynthetic activities of pelagic phytoplankton growing in the euphotic zone. Nutrient contributions from land run-off are believed to be minimal, although this has not been studied and a considerable offshore-inshore migration of mobile animals occurs. The herbivorous copepods are considered to be the most important consumers of the phytoplankton. They, in turn, are preyed upon by carnivorous zooplankton such as siphonophores, chaetognaths, and fish larvae. Secondary and tertiary carnivores, such as various fish species, prey on the primary and secondary carnivores. It should be emphasized that the food-web described represents the simplest model possible. It is safer to assume that complex food-chain relationships exist involving both biota and environment. The rudiments of these relationships are now just being learned.

Measurement of the total population of a particular animal or plant species in offshore waters has not been attempted, to our knowledge, because of technical difficulties and cost. Gross estimates of the population of some species can be made, however, based on standing crop, geographical range, and additional simplifying assumptions.

What is found by sampling organisms in the field constitutes the standing crop of that area which, of course, reflects the balance between the rates of reproduction-growth and predation, and is influenced by the sampling method. Generally, the standing crop fluctuates seasonally and yearly about a mean value. Depth and times of day may also be important considerations in its estimation, depending upon the organisms considered. This is well illustrated in table 52 by a list of plankton samples given by Owre (1960). The NG station is about 10 mi east of Miami.

Table 52. List of Plankton Samples Taken at the NG Station (from Owre, 1960)

Sample	Date	Time	Depth (m)	Wet Volume⁺ (cc)	Towing Distance (mi)
14A	1/12/51	1106	0-10	<1	2.0
14B		1157	9-27	<1	2.0
14C		1242	40-64	14	1.6
14D		?	82-91	10	1.5
14E		1416	192	18	0.95
14G		1550	182	3	0.8
25F	5/25/51	1420	183-229	4	1.0
26A	6/5/51	1020	0-50	1	1.0
26B		11[illegible]	50-100	<1	0.9
26C		1110	100-150	7	0.9
26D		1240	280-320	2	0.6
26E		1240	320-350	3	0.6
26F		1320	300-350	5	1.1
27B	6/19/51	112[illegible]	0-45	14	1.15
27C		120[illegible]	55-75	9	0.90
27D		1[illegible]	70-100	1	1.15
27E		1330	70-85	<1	1.05
28A	7/3/51	0925	0-80	27	1.70
29A	7/13/51	0900	0-60	39	2.0
29B		0955	50-95	3	0.5
29C		0955	95-140	6	0.5
29D		1040	165-210	2	0.85
29E		1040	210-255	2	0.85
29F		1140	210-300	3	0.85

Table 52 (Continued)

Sample	Date	Time	Depth (m)	Wet Volume+ (cc)	Towing Distance (mi)
30A	8/2/51	0945	0-50	12	1.5
30B		1135	105-145	3	0.6
30C		1135	145-185	9	0.6
30D		1150	160-185	5	1.2
30E		1150	185-200	5	1.2
30F		1350	225-275	20	1.5
31	8/7/51	1107	surface	11	1.2
32-1	8/28/51	1100	55	9	0.9
32-2		1100	115	7	0.9
32-3		1235	151	1.5	0.7
32-4		1235	185	4	0.7
32-5		1140	167	5	0.6
32-6		1140	242	4	0.6
37A	12/10/51	1136	9-46	22	2.0
37B		1310	69-115	2	0.45
37C		1310	119-165	4	0.45
37D		1400	151-179	3	1.1
37E		1400	201-229	5	1.1
38A	1/14/52	1010	surface	47	1.7
38B		1055	59	3	0.3
38C		1055	110	11	0.3
38D		1145	110	11	0.3
38F		1248	46	9	1.1
39A	2/4/52	1015	surface	20	3.1
39B		1105	50	13	1.2
39D		1153	96	15	2.1
39E		1153	146	8	2.1
39F		1240	96	37	2.4
39G		1240	146	13	2.4

+Mean density by wet plankton displacement volume = ~ 0.03 cc/m^3 or 1 mg dry wt/m^3 using conversion factors of Bsharah, 1957.

To place plankton standing crop and production of this region in rough perspective, the data in tables 53 and 54 should be examined. It appears that both standing crop and rate of production of phytoplankton are less in this region than in major fishery areas.

In constrast with offshore waters, a considerable amount of information is available on the ecology of inshore waters. Extensive lists of species have been compiled, and plant-animal communities have been described and related to physical-chemical-geological characteristics of inshore regions. A major

Table 53. Zooplankton Standing Crop in Offshore Areas

Number/m3	Dry Weight/m^3 (mg)	Location	Reference
12	--	Florida Current	Bsharah, 1957
239	--	Sargasso Sea	Fish, 1956
690	--	Labrador Sea	Fish, 1956
--	0.5	Florida Current	Bsharah, 1957
--	5	Gulf of Maine	Redfield, 1941
--	13	Long Island Sound	Deevey, 1956
--	9	Georges Bank	Riley and Bumpus, 1946

Table 54. Rate of Production in Offshore Areas

Location	Rate of Production $gC/m^2/yr$	Type of Production	Reference
Florida Current	67-182.5	net-gross	Corcoran and Alexander, 1963
Caribbean	51-70	net-gross	Steeman-Neilson and Jensen, 1957
Long Island Sound	470	gross	Riley, 1956
Georges Bank	309	gross	Riley et al, 1949
New York Coastal Water	160	gross	Ryther and Yentsch, 1958

report synthesizing information on the marine ecology of the Biscayne National Monument (between 25°31' N and 24°17.5' N to the 10-fathom curve) was submitted to the National Park Service by Voss et al (1969). Similarly, Morril and Olsen (1955) made a literature study of the Biscayne area for the U.S. Hydrographic Office. Other major studies have also been made. Voss and Voss (1955) surveyed the ecology of Soldier Key. Smith et al (1950) made an ecological survey of inshore waters adjacent to Miami. Moore et al (1968) have studied the fauna, epifauna, and infauna of the tidal flats in Biscayne Bay. O'Gower and Wacasey (1967) studied animal communities associated with sea grasses (Thalassia, Diplanthera) and sand beds in Biscayne Bay. Stephenson and Stephenson (1950) have described intertidal life in the Florida

Keys. McNulty et al (1960, 1962a, 1962b) and McNulty (1961) have reported on the ecological effects of sewage pollution in Biscayne Bay. Rosseler et al (1970) and Zieman (1970) have reported on the effects of thermal discharges in the same region.

The biology of molluscs in the region has been studied by Penzias (1969), Frazer (1967), Moore and Lopez (1969), and Owre (1964). Polycheates have been studied by McNulty and Lopez (1969), and sea urchins by Moore et al (1963a, 1963b), Moore and McPhearson (1965), Moore and Lopez (1966), McPhearson (1965, 1968a, 1968b, 1969), Moore and Frue (1959), and Quinn (1965). Milliman (1969), Jones (1963), and Smith (1948) have studied corals, while crabs and lobsters have been studied by Provenzano (1959, 1962, 1968, 1969), and Rice and Provenzano (1966).

Phytoplankton

The phytoplankton of tropical waters consist in large part of nanoplankton, including crysomonads, cryptomonads, naked flagellates and small diatoms (Vargo, 1968). These tiny algae are not held by conventional plankton nets and are difficult to sample. The systematics and physiology of the nanoplankton have not been investigated in detail because a method for handling these small organisms is not well developed. Nanoplankton have the reputation of being very delicate; that is, difficult to keep alive for laboratory study and to preserve for systematic study.

A map of the region and stations sampled by Vargo (1968) and others of the University of Miami is given by figure 62. The Fowey Light station (25° 40' N, 80° 00' W) is about 10 miles east of Miami and is on the eastern border of the Florida Current, in water about 300 meters deep. The biota of this station is considered representative for "shelf" and Florida Current waters.

The quantity of nanoplankton found by Bsharah (1957) in terms of dry weight, by depth and season, is given by figure 63. The data show that the greatest abundance of nanoplankton occurs in the summer and in the upper 60 meters of water column. During March the abundance is least and the distribution is uniform from the surface to 160 meters. Bsharah states that between 85 and 90 percent of the nanoplankton are found in the euphotic zone which extends to 100 meters. He found that a bloom of nanoplankton occurs during

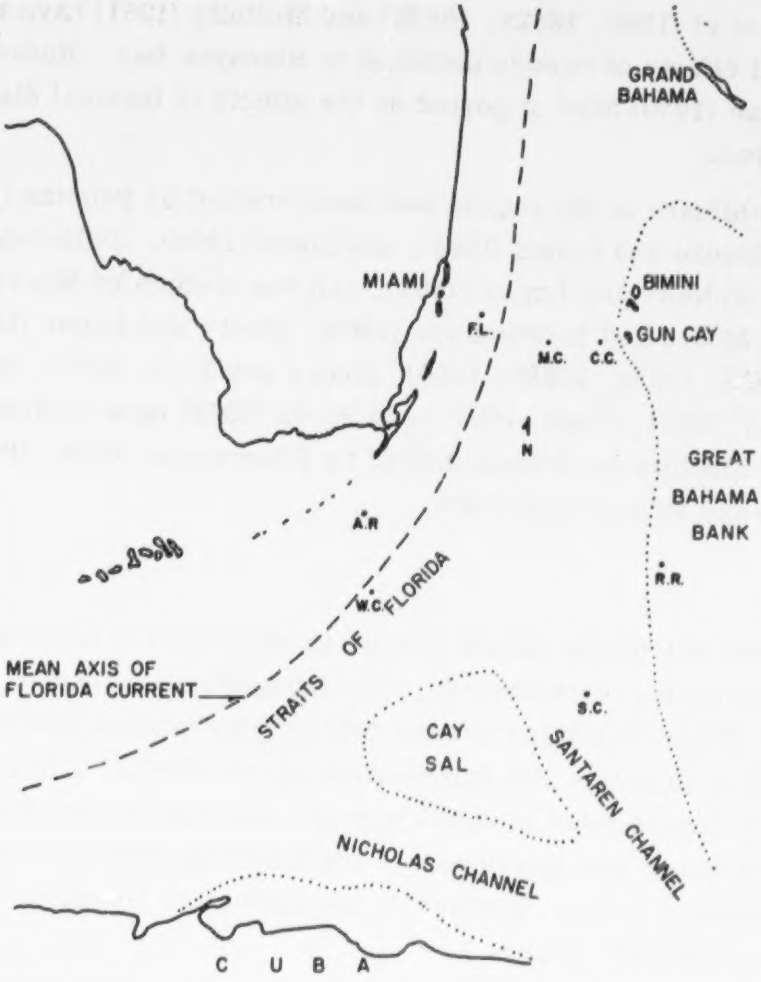

GRAND BAHAMA
MIAMI
BIMINI
F.L.
GUN CAY
M.C.
C.C.
N
GREAT BAHAMA BANK
A.R
R.R.
W.C.
STRAITS OF FLORIDA
MEAN AXIS OF FLORIDA CURRENT
CAY SAL
S.C.
SANTAREN CHANNEL
NICHOLAS CHANNEL
C U B A

Figure 62. Station Locations in Straits of Florida: FL - Fowey Light, MC - Midchannel, CC - Cat Cay, RR - Riding Rocks, SC - Santaren Channel, WC - West Channel, AR - Alligator Reef (from Vargo, 1968)

the summer months, as shown in figure 64, the increase at the height of the bloom being about seven-fold in the upper 35 meters of water. The overall effect of this summer bloom reaches slightly below the lower limit of the euphotic zone and, throughout the autumn months, occupies the upper 40 meters of water.

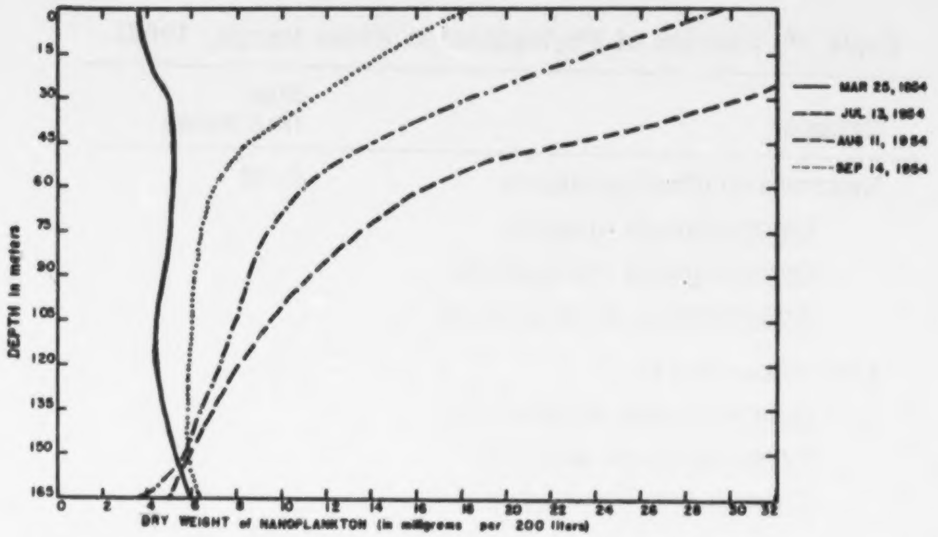


Figure 63. Typical Vertical Distribution of Nanoplankton as Dry Weight (from Bsharah, 1957)

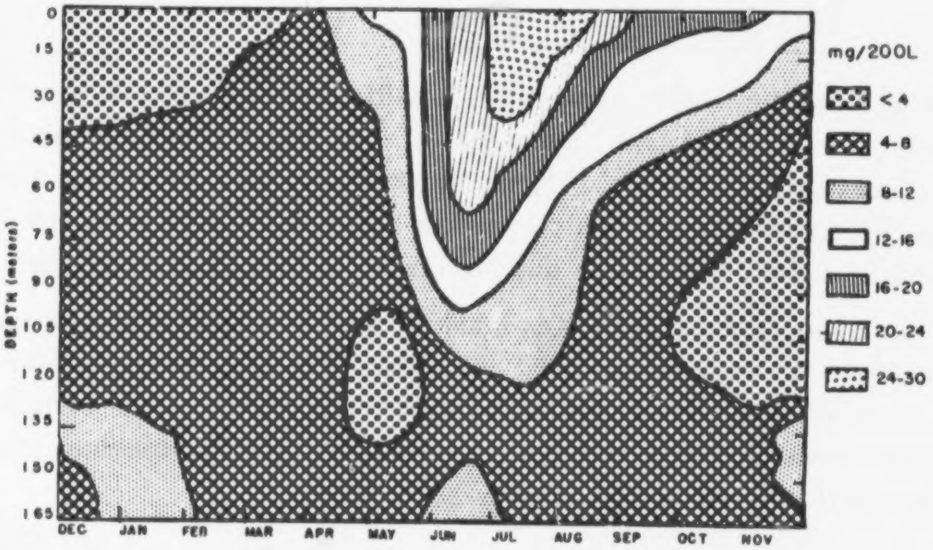


Figure 64. Seasonal Vertical Distribution of Nanoplankton as Dry Weight in Florida Current (from Bsharah, 1957)

Some of the more prominent and more easily identifiable species of phytoplankton are given in table 55.

Table 55. Species of Phytoplankton (from Vargo, 1968)

Groups	Size (microns)
Unarmored dinoflagellates	9-70
Gymnodinium simplex	
Gymnodinium rotundatum	
Amphidinium acutissimum	
Coccolithophores	--
Deutschlandia stenophylla	
Syracosphaera pulchra	
Coccolithus leptoporus	
Diatoms	200 max
Rhizosolenia styliformis	
Navicula membranacea	
Melosira moniliformis	
Cosinodiscus excentricus	
Rhizosolenia stolterforthii	

Vargo, using a smaller water sample (1L vs 200L) but a concentration procedure identical to that of Bsharah, found that peak abundances of phytoplankton generally occurred at Fowey Light during spring and winter as well as summer over a three-year period. This is shown by figure 65. The numbers of phytoplankton found at Fowey Light and his other stations are given by table 56.

Vargo further found that phytoplankton maxima occurred over a wide range of depths coincident with micropyncnal surfaces. The distributions observed by depth and month are given by figures 66 and 67. The distributions shown do not agree with Bsharah's data in that the number of phytoplankton does not drop off markedly until the depth exceeds 100 meters.

Table 56. Phytoplankton Standing Crop (from Vargo, 1968)

	1	2	3	4	5	6
Month	Fowey Rocks 25°40'N 80°00'W	Mid-channel 25°33'N 79°40'W	Cat Cay 25°35'N 79°25'W	Santaren Channel 24°05'N 79°35'W	West Channel 24°30'N 80°30'W	Alligator Reef 24°50'N 80°30'W
1964						
Jan	9.62	2.98	2.08	2.20	--	--
Feb	12.02	6.55	2.15	--	--	3.28
Mar	9.98	2.72	1.66	4.50	1.44	3.21
Apr	2.73	2.02	1.20	5.55	5.77	8.00
May	9.56	3.75	4.98	6.94	6.42	3.09
June	--	--	--	--	--	--
July	0.95	1.48	3.60	2.61	3.54	1.95
Aug	3.09	2.45	2.31	1.57	2.34	2.45
Sept	2.25	2.70	3.50	2.31	2.19	2.54
Oct	5.65	2.80	5.33	2.34	3.18	2.98
Nov	3.77	3.15	5.57	3.92	1.82	3.30
Dec	3.50	4.16	4.26	2.45	3.25	5.40
Average	5.75	3.15	3.42	3.44	3.21	3.62
1965-66						
Jan	2.60	2.50	2.21	2.30	2.55	2.43
Feb	--	--	--	21.31	8.96	5.75
Mar	9.89	16.02	16.25	15.57	15.92	8.40
Apr	4.90	3.58	3.49	6.01	10.88	14.40
May	11.69	11.81	17.45	9.64	15.05	5.57
June	3.45	2.33	2.00	2.24	4.22	1.31
July	2.42	6.52	3.33	4.50	2.50	2.35
Aug	10.78	8.71	5.51	--	--	--
Sept	3.61	2.48	1.95	2.65	1.90	1.52
Oct	3.52	2.82	1.32	1.65	--	--
Nov	2.60	1.80	2.24	3.27	2.50	1.92
Dec	9.50	13.99	5.53	6.15	6.21	3.26
Jan	3.70	2.91	2.00	2.31	1.65	1.45
Average	5.67	6.29	5.27	6.47	6.57	5.31

Number of cells = tabular value x 10^{12} cells/m^2

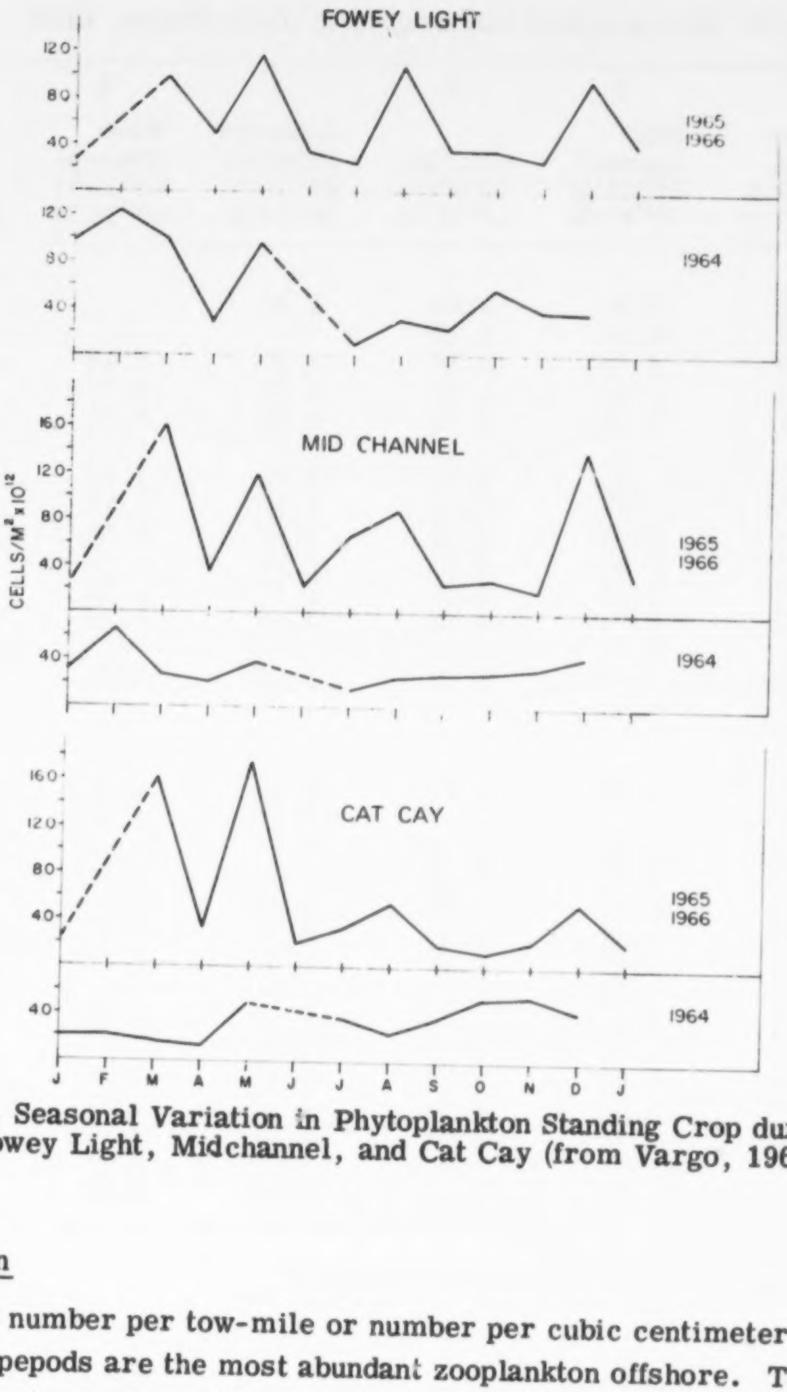
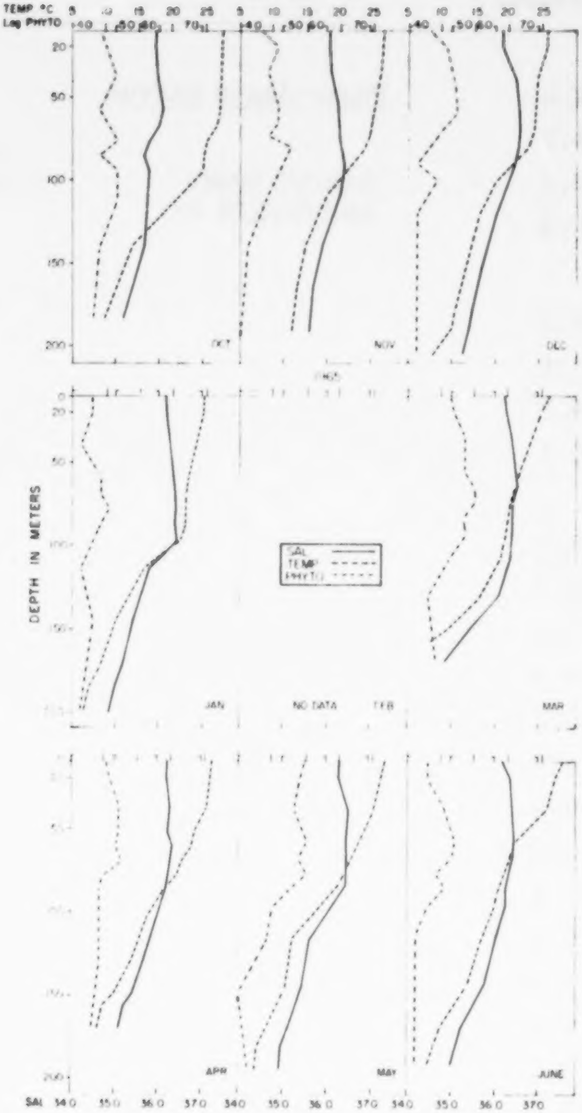


Figure 65. Seasonal Variation in Phytoplankton Standing Crop during 1964-1966 at Fowey Light, Midchannel, and Cat Cay (from Vargo, 1968)

Zooplankton

In terms of number per tow-mile or number per cubic centimeter of plankton sample, copepods are the most abundant zooplankton offshore. The next most abundant groups are the chaetognaths and the siphonophores (Bsharah, 1957). Inshore, as shown in table 57, decapod larvae, nauplii, and veliger larvae of various benthic animals constitute a substantial fraction of the zooplankton.



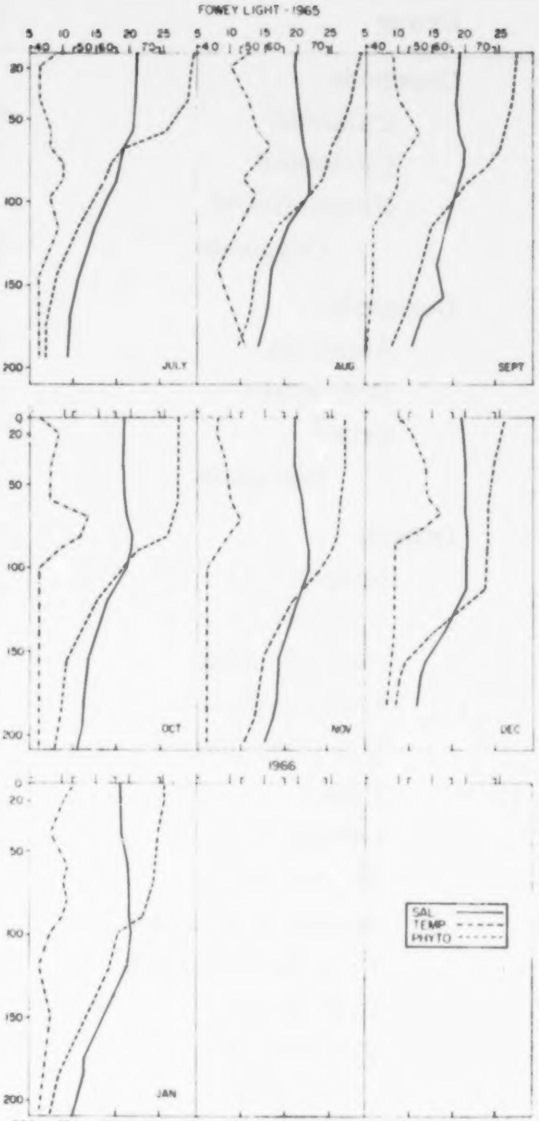


Figure 66. Vertical Distribution of Phytoplankton at Fowey Light from October 1964 to June 1965 (from Vargo, 1968)

Figure 67. Vertical Distribution of Phytoplankton at Fowey Light from July 1965 to January 1966 (from Vargo, 1968)

Table 57. Percentages of Major Groups of Zooplankton Taken with No. 2 Net (0.366 mm Porosity) in Biscayne Bay (from McNulty et al, 1960)

Group	Percent	
Copepods		
Calanoid	62.8	*Paracalanus parvus*
Cyclopoid	3.3	
Herpacticoid	0.4	*Acartia tonsa*
Copepods	66.5	*Labidocera* sp.
Decapods		
Anomura	13.5	
Brachyura	1.8	
Other	5.0	
Decapods	20.3	
Others		
Nauplii	5.9	
Veligers	3.7	
Chaetognatha	1.1	
Leptomedusae	0.7	
Mosquito larvae	0.5	
Plutei	0.3	
Larvacea	0.2	
Pteropoda	0.2	
Stomatopod larvae	0.1	
Polychaete larvae	0.1	
Fish larvae	0.1	
Forminifera	0.1	
Cladocera	0.1	
Cumacea	0.1	

Copepods

Owre and Foyo (1967) have prepared an excellent monograph on the systematics of 216 copepods species found in the Florida Current. Tables of common species are also presented. The species of copepods common throughout the year and their vertical distribution during the day and night are given in table 58 (Roehr and Moore, 1965). It is safe to assume that seasonal variation in abundance of copepods as a group is not large, or this aspect certainly would have been mentioned by the Miami scientists. The data show that the upward migration at night is greatest for *Pleuromamma xiphias*, a deep-living copepod. Shallower-living copepods migrate less or not at all, and a number of them reverse the normal pattern and move upward in the daytime and downwards at night. The extreme case is *Corycaeus lautus*, which migrates downward 41 meters. Graphs by Moore and Foyo (1963) indicate "shallow" and "deep" species as those found at day-depths of 40-380 meters and 160-400 meters, respectively.

Table 58. Vertical Distribution of Copepods
(from Roehr and Moore, 1965)

Species	30 Percent Level*(m)				
	Day	**	Night	**	Range
Calocalanus pavo (Dana)	37	26	62	21	-25
Corycaeus lautus Dana	102	11	143	5	-41
Copilia mirabilis Dana	107	21	105	19	2
Corycaeus speciosus Dana	111	19	100	17	11
Pontellina plumata (Dana)	120	6	143	8	-23
Temora stylifera (Dana)	132	20	110	17	22
Undinula vulgaris (Dana)	134	32	85	26	49
Eucalanus attenuatus (Dana)	143	29	144	26	-1
Macrosetella gracilis (Dana)	143	28	153	23	-10
Euchaeta marina (Prestandrea)	154	33	104	29	50
Haloptilus longicornis (Claus)	175	12	184	8	-9
Lucicutia flavicornis (Claus)	185	19	141	19	44
Euaetidius giesbrechti (Cleve)	205	2	153	4	52
Pleuromamma gracilis (Claus)	244	19	158	19	86
P. abdominalis (Lubbock)	246	30	155	29	91
Rhincalanus cornutus (Dana)	246	30	186	27	60
Pleuromamma xiphias (Giesbrecht)	350	15	164	19	186

*30% level = modal depth of population

**Figures in these columns show number of stations from which mean values were obtained.

The control of vertical distribution and diurnal migration of copepods and other zooplankton is attributed to at least three environmental factors: temperature, light, and pressure (Moore and Corwin, 1956). Effects of environmental stimuli on vertical distribution are elaborated in additional papers by Moore and Bauer (1960), and Moore and Roehr (1966). Moore (1967) states that deeper living species generally prefer less illumination, higher pressure and, surprisingly, higher temperature.

At night, the greatest concentration of copepods, measured by displacement volume, is in the upper 100 meters of the water column while, in terms of numbers, the maximum night concentration is between 100 and 200 meters. This difference is explained by Moore and O'Berry (1957) by the fact that most of those copepods close to the surface in the daytime are small species while the larger ones, in general, live deeper. Owre and Foyo (1967) also note that deeper living species of copepods tend to be larger.

Chaetognaths

The chaetognaths in the Florida Current have been studied by Owre (1960, 1963). A list of species and their relative abudance is presented in table 59. Sagitta enflata, S. serratodentata, and Pterosagitta draco account for about 75 percent of chaetognaths.

Table 59. Total Counts and Percentages of Chaetognaths at the NG Station and at SL 18 (from Owre, 1960)

Species	NG Total Numbers	Percent of Total	SL 18 Total Numbers	Percent of Total
Sagitta enflata	34,398	54.5	467	14.7
S. hexaptera	484	0.8	145	4.5
S. lyra	427	0.7	67	2.1
S. bipunctata	2,980	4.7	52	1.6
S. hispida	857	1.4	12	0.4
S. helenae	318	0.5	0	0.0
S. serratodentata	12,598	19.9	1,714	54.0
S. minima	3,956	6.3	4	0.1
S. decipiens	1,160	1.8	208	6.5
S. planctonis	1	< 0.1	1	< 0.1
S. macrocephala	1	< 0.1	1	< 0.1
Pterosagitta draco	3,907	6.2	233	7.3
Krohnitta subtilis	468	0.7	97	3.1
K. pacifica	1,518	2.4	166	5.2
Eukrohnia hamata	1	< 0.1	0	0.0
E. fowleri	0	0.0	2	< 0.1

NG: 25° 43' to 26° 08' N, 79° 56'W. SL18: about 40 mi east of Miami

Species collected in adequate numbers are at peak abundance in the summer, generally coinciding with their breeding period according to Owre, as shown by figure 68. Owre found that the vertical distribution of the chaetognaths varied greatly with season at the two stations studied. She believes this was caused principally by reaction to temperature (see also Moore, 1955).

The three most abundant species were found to migrate diurnally. The seasonal variation and vertical distribution of *Sagitta enflata*, the most abundant species, is shown by figure 69. Comparison of the chaetognaths from the NG station with those from the SL station (a distance of about 30 mi) showed slight differences in species composition but marked differences in relative abundance and, especially, in vertical distribution as shown by figure 70.

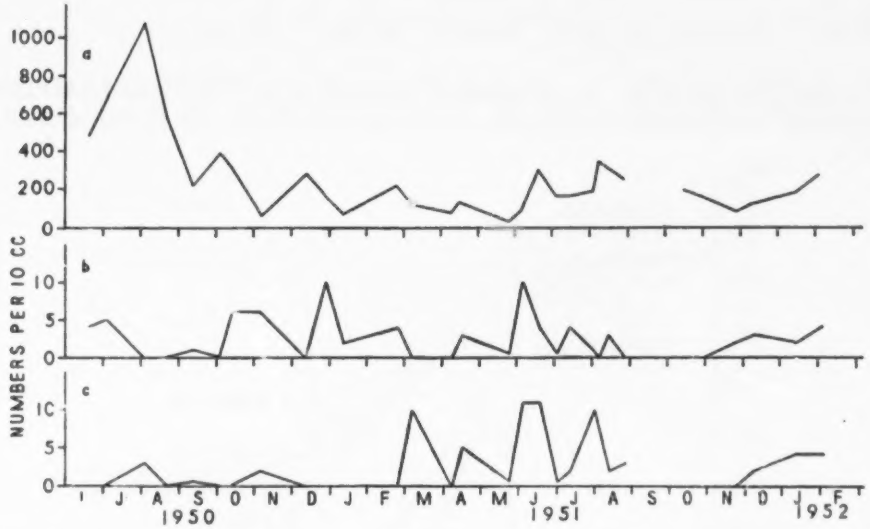


Figure 68. Seasonal Variation in Abundance of: a. *Sagitta enflata*, b. *S. hexaptera*, and c. *S. lyra* (from Owre, 1960)

Siphonophores

The siphonophores in the plankton have been studied by Moore (1953). The species commonly found include *Abylopsis tetrogona*, *A. eschscholtzii*, *Bassia bassensis*, *Chelophyes appendiculata*, *Diphes bojani*, *D. dispar*, *Eudoiodes spiralis*, and *E. mitra*. These eight species make up about 90 percent of the siphonophore population.

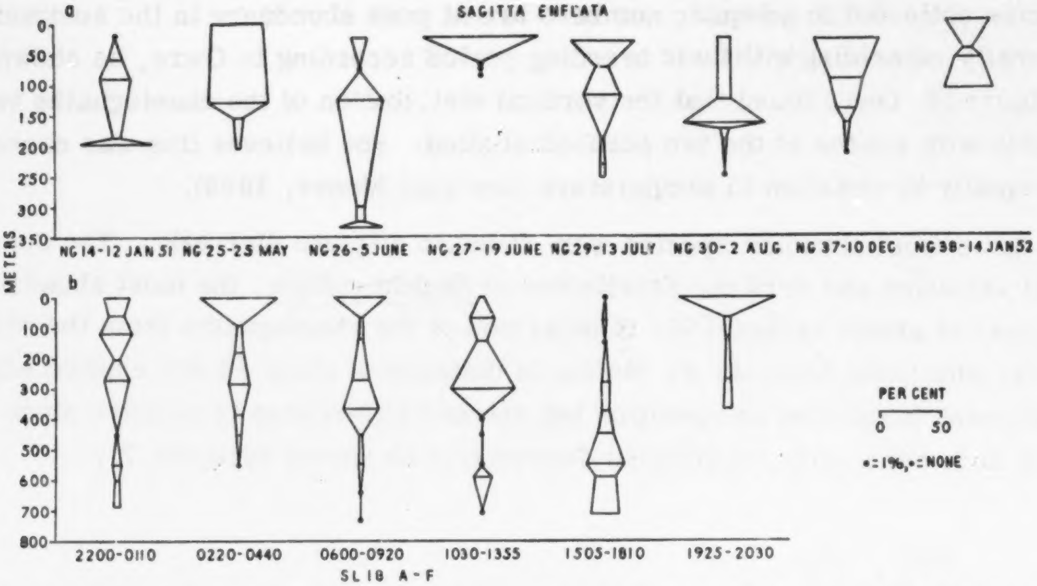


Figure 69. Sagitta enflata: a. Seasonal Variation in Vertical Distribution at the NG Station; b. Diurnal Vertical Distribution at SL 18 (from Owre, 1960)

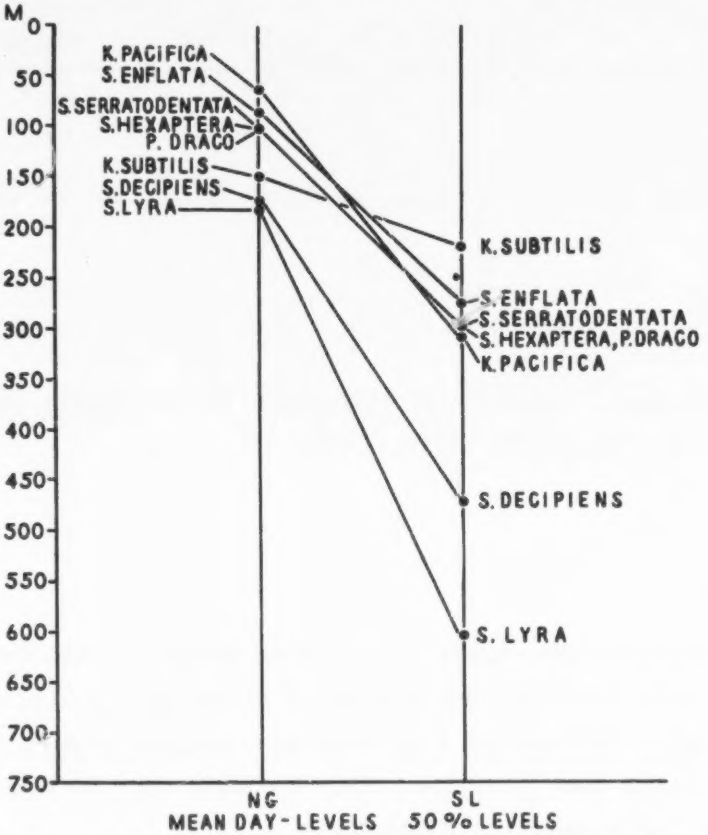


Figure 70. Comparison of Depths of Mean Day-Levels at the NG Station with Depths of 50 Percent Levels at the SL Station (from Owre, 1960)

The seasonal distribution of some of the more abundant species is given in figure 71. The vertical distribution and diurnal migration are given in tables 60 and 61. Moore (1955) states that light, temperature and, perhaps, pressure are responsible for the distributions observed.

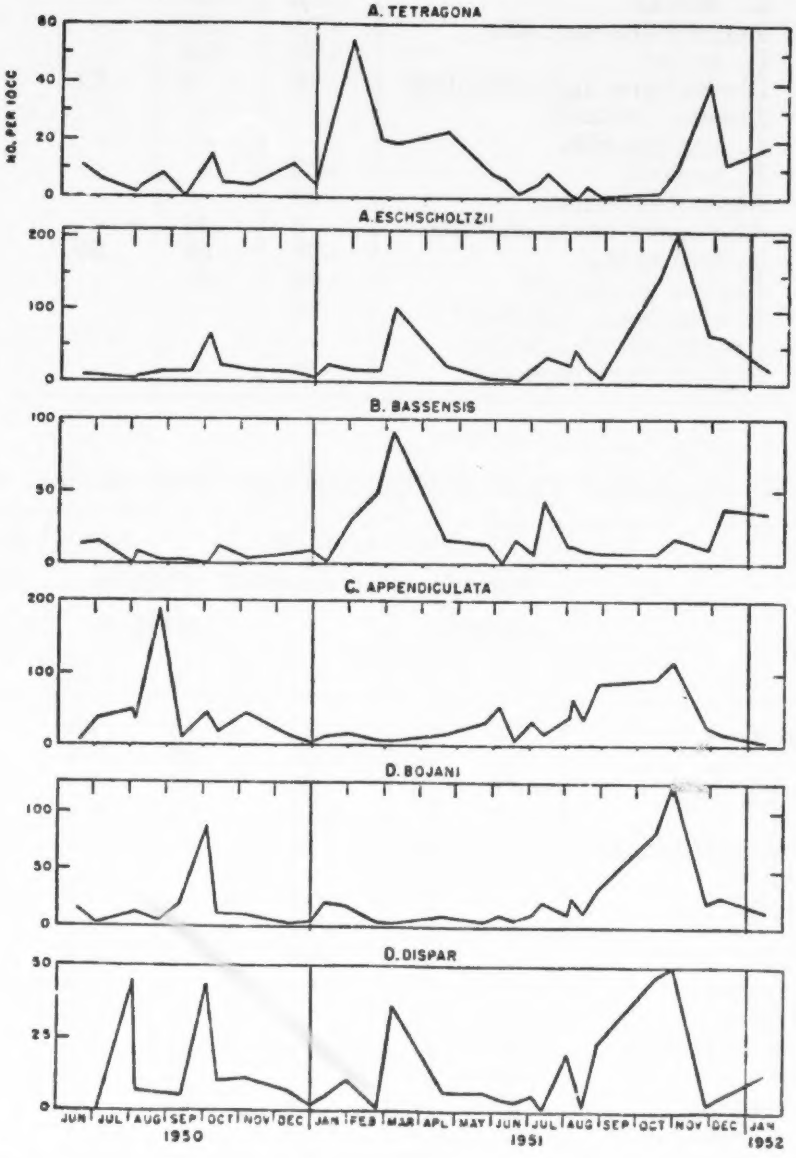


Figure 71. Seasonal Distribution of Siphonophores (from Moore, 1953)

Table 60. Diurnal Migration of Siphonophores (from Moore, 1953)

Species	Day-Night Range (m)		
	Florida		Bermuda
	NG 16	NG 32	
Diphyes bojani	-59	-16	-
D. dispar	-38	+49	-
Eudoxoides spiralis	-33	-30	-
E. mitra	-50	-44	-
Chelophyes appendiculata	-48	- 5	-87
Lensia cossack	-	-	-
L. campanella	-	-	-
L. fowleri	-32	-	-
Abyla leuckartii	-92	-	-
Abylopsis eschscholtzii	- 6	-48	-
A. tetragona	-70	-80	-89
Bassia bassensis	-28	-41	-
Enneagonum hyalinum	-19	-	-
Amphicaryon acaule	-	-	-77
Hippopodius hippopus	-50	-	-

Table 61. Mean Day Level of Siphonophores (from Moore, 1953)

Species	Mean Day Level (m)			Spread (m)		
	Florida Method		Bermuda	Florida Method		Bermuda
	I	II		I	II	
Diphyes bojani	72	29	40	43	88	25
D. dispar	59	40	ca.10	76	104	10
Eudoxoides spiralis	75	50	65	45	69	65
E. mitra	134	68	125	65	134	105
Chelophyes appendiculata	74	48	75	81	100	130
Lensia cossack	--	35	--	--	43	--
L. campanella	--	17	60	--	25	25
L. subtilis	--	32	140	--	30	150
L. fowleri	--	100	165	--	102	70
Galetta australis	--	58	--	--	84	--
Abyla leuckartii	--	102	--	--	105	--
Abylopsis eschscholtzii	58	12	ca.40	51	78	80
A. tetragona	104	85	55	63	122	25
Bassia bassensis	59	13	50	29	75	40
Enneagonum hyalinum	--	100	--	--	28	--
Amphicaryon acaule	--	92	80	--	100	75
Hippopodius hippopus	--	110	140	--	92	75

Larval Fish

Although not abundant in plankton hauls (perhaps because of the difficulty in capturing them with plankton nets) older stages of larval fish have rather extensive diurnal migrations as shown by figures 72, 73, and 74. Sund and Richards (1965) describe sea trials of a high-speed neuston net off Miami, but provide no data on the relative efficiency of the net in capturing fish larvae near the surface.

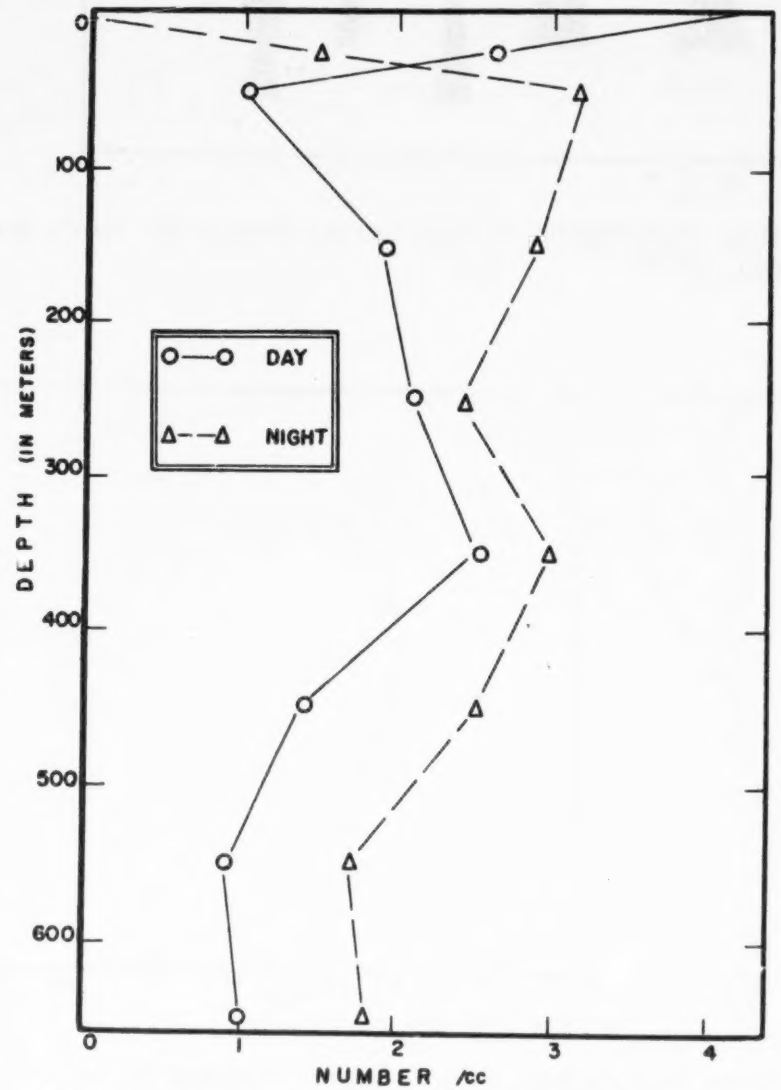


Figure 72. Vertical Distribution of Post-Larval Fish per Cubic Centimeter of Plankton at the Forty-Mile Station: Day, 12-16 hr; Night 20-04 hr (from Bsharah, 1957)

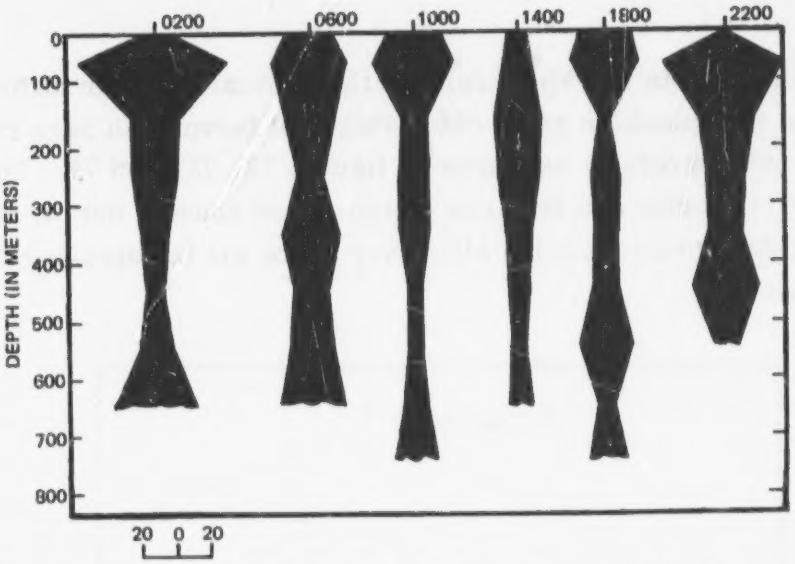


Figure 73. Vertical Distribution of Post-Larval Fish at the Forty-Mile Station (from Bsharah, 1957)

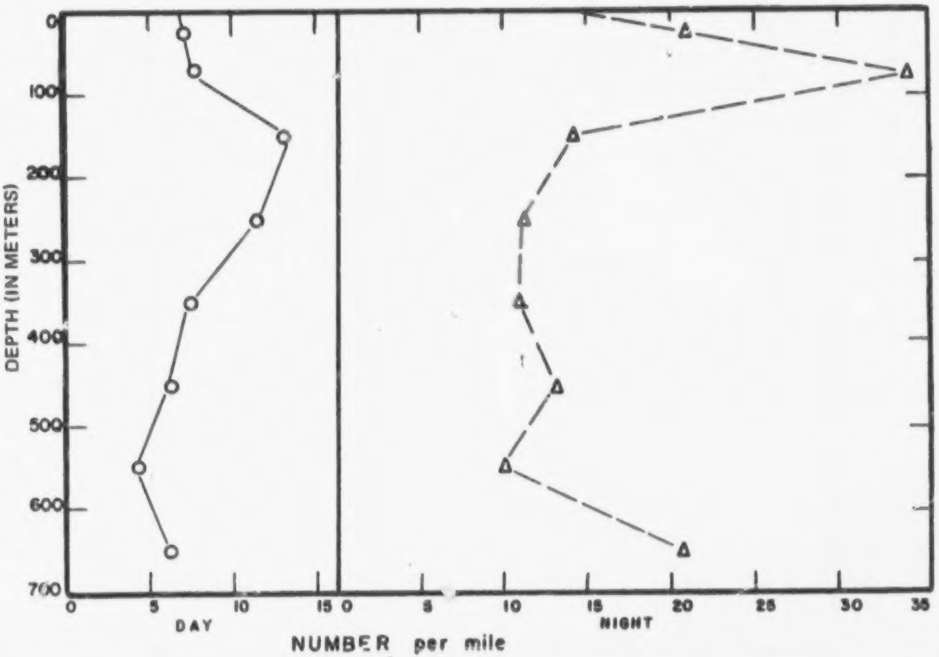


Figure 74. Vertical Distribution of Post-Larval Fish per Mile Tow at the Forty-Mile Station: Day, 12-16 hr; Night, 20-08 hr (from Bsharah, 1957)

Several people have studied the life histories of various groups of fish in this region. Further information on fish larvae can be found in Voss (1954), Clancey (1956), Legaspi (1956), and Voss (1953). The University of Miami Marine Library has on file many unpublished theses on the marine fish of the Miami region.

Other less abundant groups of zooplankton offshore have been studied. The euphausiids have been the subject of study by Lewis (1954), the pteropods by Wormelle (1962), and the cephalopods by Voss (1955, 1956).

Principal Fisheries

The principal commercial fisheries on the east coast of Florida are given in table 62. In terms of landings and dollar value, the shrimp, spiny lobster, and king mackerel fisheries are the three most important. Details on the shrimp fishery are given in table 63 and in figures 75 and 76. Details on the spiny lobster and spanish mackerel fisheries are presented in tables 64 and 65. Of the fish listed in table 62, only the snapper and grouper are demersal.

Table 62. Florida Landings, East Coast, 1969
(from Johnson, 1969)

Fishery	Pounds	Value
Fish		
King mackerel	2,942,841	$ 598,539
Black mullet	2,384,343	189,302
Spanish mackerel	2,358,874	253,336
Bluefish	2,080,292	232,919
Spot	874,647	158,404
Spotted sea trout	679,697	229,509
Red snapper	634,772	366,837
Grouper	522,243	110,885
Pompano	332,838	324,094
Crustaceans		
Spiny lobster	2,928,569	1,932,852
Shrimp	5,188,108	3,297,913

Table 63. Details on the Shrimp Fishery

Pink shrimp	*Penaeus duorarun*
Brown shrimp	*P. aztecus*
White shrimp	*P. setiferus*

Characteristics		Data Source*
Commercial landings (lb)	5,188,108	1
Economic importance ($)	3,297,915	1
Geographical range	Chesapeake Bay to Gulf of Mexico	2,3
Habitat preferences		
Water depth	6 to 20 fathoms	3,4
Temperature range	3 to 35.5°C	3
Salinity range	0 to 37 °/oo	3
Type of bottom	firm bottom; mud-sand containing mollusc shell	3
Food sources		
Larvae	unicellular algae	5
Adults	bottom nocturnal feeder; ominivorous; algae and plant detritus	3
Growth first year	--	
Mobility-migration		
Vertical	postlarvae and beyond active swimmers	6
Horizontal	move from shallow to deep water during winter	3,7
Behavioral characteristics	larvae near surface at hight, postlarvae active day and night, juveniles and adults nocturnal	
Spawning		
Area	adults offshore; post larvae transported inshore to nursery grounds	3
Time of year	spring, summer, fall, copulation no specific time	3
Position of eggs/larvae in water column	eggs demersal, larvae pelagic	3
Larvae development time	15 to 25 days	3,5

*1. Johnson, 1969
2. Heald, 1968
3. Farfante, 1969
4. Anderson, 1970
5. Ewald, 1965
6. Knopf, 1970
7. Costello and Allen, 1966

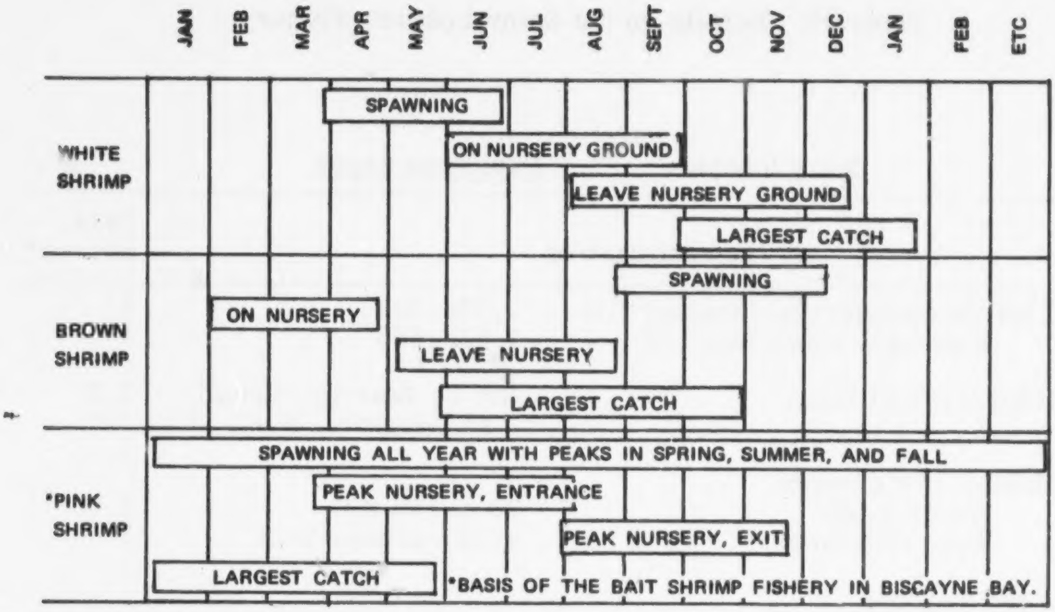


Figure 75. Species Variations on the Biological Life Cycle (from Knopf, 1970)

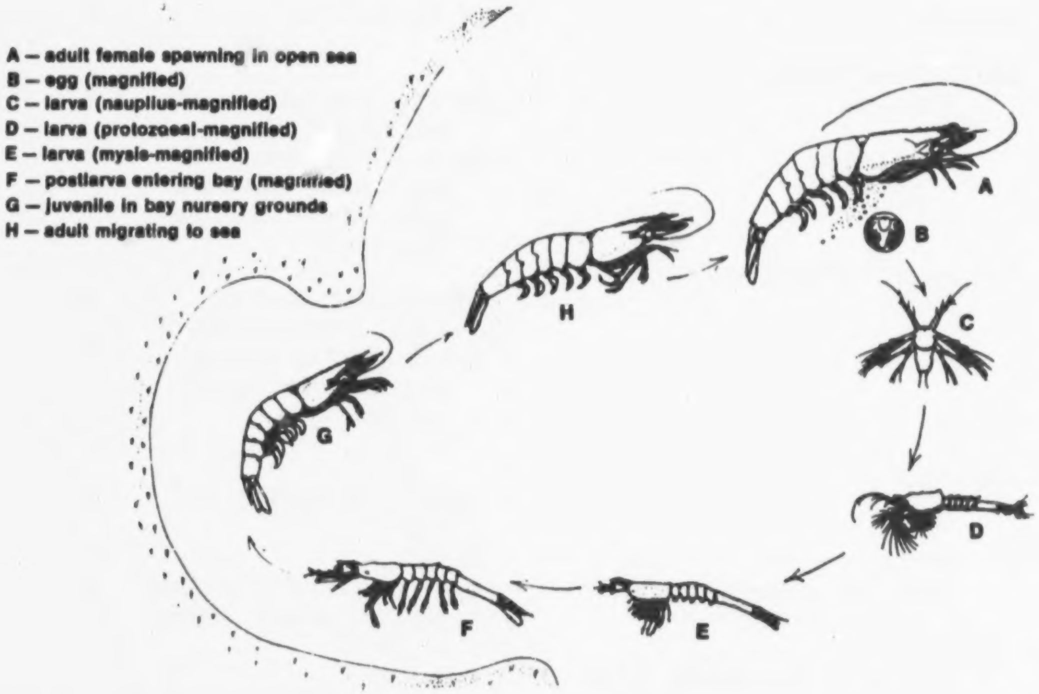

A – adult female spawning in open sea
B – egg (magnified)
C – larva (nauplius-magnified)
D – larva (protozoeal-magnified)
E – larva (mysis-magnified)
F – postlarva entering bay (magnified)
G – juvenile in bay nursery grounds
H – adult migrating to sea
A
B
C
D
E
F
G
H

Figure 76. Life Cycle of Shrimp (from Knopf, 1970)

Table 64. Details on the Spiny Lobster Fishery

Spiny lobster	*Panulirus argus*	
Characteristics		Data Source*
Florida commercial landings (lb)	2,928,569	1
Economic importance ($)	1,932,852	1
Geographical range	Rio de Janeiro, Brazil to Beaufort, N.C.	2,3
Habitat preferences		
Water depth	30 to 180 ft	2,4
Type of bottom	rocky-grassy bars	2
Food sources		
Larvae	--	
Adults	scavengers, small molluscs	2
Growth	10 in. in 4 yr	2
Mobility-migration		
Vertical	larvae exhibit diurnal migration	2
Horizontal	up to 100 mi but generally 5 mi,	2
	inshore Apr-June, offshore Dec-Jan	2
Behavioral characteristics		
Light	larvae attracted by light, adults avoid it	2
Currents	adults dislike strong currents and mud bottom	2
Spawning		
Area	mate inshore Feb to Apr	2
Time of year	June	2
Position of eggs/larvae in water column	eggs attached to female; pelagic to water depths of 130 ft	2,3
Larvae development time	3 to 6 mo	5

*1. Johnson, 1969 2. Smith, 1958
3. Robinson and Dimitriou, 1963 4. Heald, 1968 5. Sims, 1966

Table 65. Details on the Spanish Mackerel Fishery

Spanish mackerel __Scomberomorus maculatus__

Characteristics		Data Source*
Commercial landings (lbs)	2,358,874	1
Ecomonic importance ($)	253,336	1
Geographical range	Chesapeake Bay to Brazil	2,4
Habitat preferences		
Water depth	12 to 40 fathoms	2,3
Temperature range	within 68° isotherm	3
Salinity range	estuarine to oceanic	4
Type of bottom	no preference	4
Other	occur out to slope	4
Food sources		
Fry	copepod larvae and eggs, pelagic crustacea, fish larvae	4
Adults	herring-like fish	3
Growth first year	50 cm; 8-9 in.	3,4
Mobility-migration		
Vertical	20-30 fathoms	4
Horizontal	offshore in winter, inshore in spring	4
Behavioral characteristics		
Schooling	dense near surface; good swimmers	4
Spawning		
Area	Cape Hatteras to Cape Cod	4
Time of year	spring and early summer	4
Position of eggs/larvae in water column	pelagic	
Larvae development time	--	

1. Johnson, 1970 2. Heald, 1968 3. Klima, 1959
4. Bigelow and Schroeder, 1953

Sport Fishing

Sport fishing is extremely important to the tourist economy of southeastern Florida (Ellis et al, 1958; Voss et al, 1969). It was best summarized by Dr. Donald de Sylva, a specialist at the Institute of Marine and Atmospheric Sciences, University of Miami, in the report by Voss et al (1969). An excerpt follows:

> The Rickenbacker Causeway study (Biscayne Bay) was done over a period of 21 months between July 1960 and October 1962 by Dr. Richard A. Wade and, in part, by Dr. Henry A. Feddern. During this time, 2,148 specimens belonging to 98 species of marine fishes were measured and examined in detail. The species, in order of abundance, were as follows:
>
> 1. Spanish mackerel, *Scomberomorus maculatus*
> 2. White grunt, *Haemulon plumieri*
> 3. Crevalle jack, *Caranx hippos*
> 4. Gray snapper, *Lutjanus griseus*
> 5. Lane snapper, *L. synagris*
> 6. King mackerel, *Scomberomorus cavalla*
> 7. Bluestriped grunt, *Haemulon sciurus*
> 8. Bluefish, *Pomatomus saltatrix*
> 9. Sailor's choice, *Haemulon parrai*
> 10. Pigfish, *Orthopristis chrysopterus*
> 11. Mutton snapper, *Lutjanus analis*
> 12. Leatherjacket, *Oligoplites saurus*
> 13. Sand perch, *Diplectrum formosum*, and tomtate, *Haemulon aurolineatum*
> 14. Planehead filefish, *Monacanthus hispidus*, and ladyfish, *Elops saurus*
> 15. Porkfish, *Anisotremus virginicus*
> 16. Atlantic moonfish, *Vomer setapinnis*
> 17. Spotfin mojarra, *Eucinostomus argenteus*
> 18. Pinfish, *Lagodon rhomboides*
> 19. Inshore lizardfish, *Synodus foetens*
> 20. Yellowfin mojarra, *Gerres cinereus*
> 21. Pompano, *Trachinotus carolinus*, and black grouper, *Mycteroperca bonaci*
> 22. Snook, *Centropomus undecimalis*
>
> Ten species comprised 65 percent of the sport catch on Rickenbacker Causeway, while 25 of the 98 species constituted 87 percent of the catch.
>
> Spanish mackerel are a mainstay of the sport and commercial fishery of Biscayne Bay and Florida as a whole. Their abundance and future will probably depend upon suitable estuarine or coastal habitat for the juveniles. This migratory species spawns in the coastal waters off Biscayne Bay, and the young subsequently utilize the shallow, grassy parts of the Bay as nursery grounds. The adults roam freely throughout the grass beds and channels of the Bay, primarily in fall, winter and spring, feeding upon herring, anchovies, and shrimp.

Grunts (family Pomadasyidae) are an extremely important part of the sport fisherman's catch. The importance of these fishes in the southeast is reflected in the U.S. Fish and Wildlife Service's Hunting and Fishing Survey for 1960, in which it was found that this group was the most abundantly represented in angler catches in the southeastern United States.

Crevalle jack, primarily a sport fish, is also an important predator in the food web of south Florida and common throughout Biscayne Bay. Because of their large size and strong fighting qualities they are much sought by anglers.

Snappers, especially the gray snapper, are widespread throughout Biscayne Bay, especially in the deeper channels and about reefs or other protective habitats. They are important both to sport and commercial fisherman.

Equally sought after by the angler who desires Spanish mackerel are the king mackerel and bluefish. They occur in large schools during spring and fall and are much in demand by everyone because of their delicate flavor and excellent fighting qualities. Both species spawn offshore, but the young utilize the coastal waters east of Biscayne Bay. The adults probably use Biscayne Bay primarily as a source of food.

All of the above species utilize the Bay as a feeding or nursery ground or both at some state of their life histories. They are sought after near bridges, jetties, pilings, in the deep channels, in and about the deeper mangrove bayous, and in the passes between the islands fringing Biscayne Bay.

Not taken by anglers during the Rickenbacker Causeway survey is the spotted seatrout, Cynoscrion nebulosus. This species is common to abundant along the western edge of the Bay over grassy bottom, and is heavily fished for about Featherbed Banks. In the deep cuts between the islands and on ocean side of the islands of Biscayne Bay are numerous barracuda, Sphyraena barracuda, from 3 to 20 pounds, which afford excellent sport to the angler. Groupers, Epinephelus and Mycteroperca, as well as mutton snapper, Lutjanus analis, and yellowtail snapper, Ocyurus chrysurus, are taken over the coastal reefs bordering Elliott, Sands, and Old Rhodes Keys. Permit, Trachinotus falcatus, are sought after about the deep, sandy holes between grass beds, while bonefish Albula vulpes, of near-record size abound between Cape Florida and Sands Key, making this region one of the top areas in the world for bonefish angling. Snook and tarpon, Megalops atlantica are caught virtually beneath the branches of mangrove trees ringing Biscayne Bay's islands. All species occur within the Biscayne National Monument, and are occasionally the subject of heavy fishing pressure, especially on weekends.

Also important are the large gamefish sought offshore. A list of these species is presented in table 66. These fish spawn and migrate over such vast areas of ocean that they can be ignored for purposes of this study.

Table 66. List of Offshore Sport Fishes
(from Voss, 1967)

Acanthocybium solanderi (wahoo)
Alectis ciliaris (African pompano)
Auxis thazard (frigate mackerel)
Caranx hippos (jack crevalle)
Coryphaena equisetis (dolphin)
C. hippuris (dolphin)
Elegatis bipinnulatus (rainbow runner)
Euthynnus pelamis (oceanic bonito)
Istipophorus platypterus (sailfish)
Makaira nigricans (blue marlin)
Thunnus alalunga (albacore)
T. haynnus (bluefish tuna)
Xiphias gladius (swordfish)

Benthic Organisms

Papers on benthic studies of plants and animals offshore were not discovered. Moore (1963) has studied *Thalassia testudum*, but this plant should not be found at the depth we are considering. Nevertheless, because of its importance it will be discussed briefly. Moore studied the distribution of *Thalassia* in the United States. The results of his studies indicate that it occurs in tropical or subtropical waters and occasionally in the warmer part of temperate waters. It does not grow in areas where salinities are more than 45 ^{o}/oo or less than 20 ^{o}/oo. Water clarity limits its growth at depth, but even in the most transparent waters it does not occur at depths exceeding 11 meters. The presence of grass beds in offshore waters depends on reduced wave action. Where present, *Thalassia* beds support very abundant animal life.

Molluscs of commercial significance apparently do not occur either offshore or inshore in the Miami region. There is a calico scallop fishery farther north off the east coast of Florida, and it should be noted that Emery et al (1970) observed scallops in their dive off West Palm Springs. A list of molluscs and other benthic organisms found in Biscayne Bay is presented in table 67.

Table 67. List of Benthic Organisms in Biscayne Bay (from McNulty, 1962)

Summary, for all stations, of the mean numbers of individuals per m^2, in relation to median grain size. ^{x} indicates species considered to be epifauna, ^{o} species considered to be cryptic fauna, using the sediment for shelter but not for food. Unmarked species are considered to be true infauna.

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Porifera				
Chondrilla nucula^x (Schmidt)	--	0.12	--	0.22
Haliclona viridis^x (Duchassaing & Michelotti)	--	--	0.17	--
H. sp.^{x}	--	--	--	0.22
Higginsia strigilata^x (Lamarck)	--	--	0.17	--
Ircinia fasciculata^x (Pallas)	--	--	0.17	--
Pellina carbonaria^x (Lamack)	--	0.24	--	0.22
Tethya diploderma^x Schmidt	--	0.12	--	--
Verongia longissima^x (Carter)	--	0.24	--	--
Alcyonaria				
Telesto sanguinea^x Deichmann	--	--	0.17	--
Madreporaria				
Cladocora arbuscula^x (Le Sueur)	--	0.48	0.17	--
Porites porites^x (Pallas)	--	0.12	--	0.22
Echinoidea				
Encope michelini Agassiz	--	--	0.17	--
Lytechinus variegatus^x (Leske)	0.63	0.12	--	--
Mellita quinquiesperforata (Leske)	--	0.12	--	--

Table 67 (Cont'd)

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Echinoidea				
Moira atropos (Lamarck)	--	2.18	--	--
Asteroidea				
Asterina folium^x (Lutken)	--	--	0.17	--
Astropecten duplicatus Gray	--	0.12	--	--
Ohpiuroidea				
Amphiodia pulchella (Lyman)	0.94	0.61	--	0.44
A. trychna H. L. Clark	--	--	0.17	--
A. sp.	--	--	--	0.44
Amphioplus abditus Verrill	0.31	0.97	--	--
A. coniortodes H. L. Clark	6.88	4.00	1.16	--
Ophiactis sp.^{x}	--	--	0.17	0.22
Ophiocoma echinata^x (Lamarck)	--	0.12	--	--
Ophioderma brevispina^x (Say)	1.88	0.85	0.99	0.89
Ophiolepis paucispina^x (Say)	--	--	--	0.44
Ophiomyxa flaccida^x (Say)	--	0.12	--	--
Ophionephthys limicola Lutken	3.75	2.55	0.17	--
Ophionereis reticulata^x (Say)	0.31	2.30	--	--
Ophiophragmus pulcher H. L. Clark	0.31	0.12	--	0.67
O. sp.	--	--	0.17	--
Ophiopsila riisei^x Lutken	1.25	3.15	2.15	--
O. sp.^{x}	--	--	0.17	--
Ophiostigma isacanthun (Say)	--	0.36	0.17	0.22

Table 67 (Cont'd)

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Ohpiuroidea				
Ophiothrix oerstedii^{x} Luken)	--	1.21	--	--
O. sp.^{x}	3.13	1.21	--	--
Holothuroidea				
Euapta lappa^{x} (Muller)	0.31	0.36	--	--
Holothuria floridana^{x} Pourtales	--	--	--	0.22
Polychaeta				
Ammotrypane sp.	--	0.24	0.17	--
Arabella iricolor (Montagu)	0.63	--	--	--
Chloeia viridis^{x} Schmarda	--	--	0.17	--
Cistenides gouldi Verrill	--	0.12	--	--
Eunice rubra^{o} Grube	--	--	--	0.22
Glycera sp.	--	--	--	0.22
Hesione picta^{x} Muller	--	0.12	--	--
Loimia medusa^{x} (Savigny)	--	0.73	--	--
Lumbrineris maculata (Treadwell)	0.63	0.61	--	--
Nainereis sp.	--	0.12	--	--
Pista cristata (Muller)	1.25	--	--	--
P. sp.	0.31	--	--	--
Scoloplos rubra (Webster)	--	--	--	0.22
Sthenelais boa (Johnston)	1.25	0.85	0.17	--
Terebellides sp.	0.31	--	--	--

Table 67 (Cont'd)

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Sipunculoidea				
Phascolion sp.	0.94	--	--	--
Scaphopoda				
Dentalium antillarum (d'Orbigny)	--	--	--	0.22
Gastropoda				
Astraea tecta americana^x (Gmelin)	--	--	--	0.22
A. phoebia^x Roding	--	--	--	0.22
Atys sandersoni Dall	0.31	--	--	--
Bulla striata^x Bruguiere	1.56	0.24	--	--
Calliostoma jujubinum^x Gmelin	--	--	--	0.22
Cerithium algicola^x C. B. Adams	0.31	0.36	--	--
Columbella mercatoria^x Linne	--	0.12	--	--
C. rusticoides^x Heilprin	--	0.12	0.17	--
Conus jaspideus^x Gmelin	--	0.12	--	--
C. stearnsi^x Conrad	--	0.12	--	--
Haminoea sp.^{x}	0.31	--	--	--
Hyalina avenacea^x (Deshayes)	--	0.12	--	--
Leucozonia nassa^x (Gmelin)	--	--	--	0.22
Modulus modulus^x (Linne)	--	0.48	0.33	--
Murex recurvirostris rubidus^x F. C. Baker	--	0.12	--	--
Nassarius ambiguus^x (Montagu)	0.94	0.85	0.33	--
Natica canrena^x (Linne)	--	0.24	--	--
Nitidella nitidula^x (Sowerby)	--	--	--	0.44

Table 67 (Cont'd)

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Gastropoda				
Nitidella ocellata (Gmelin)	--	0.48	--	--
Prunum apicinum^x(Menke)	0.31	0.24	0.33	--
P. carneum^x (Storer)	--	--	--	0.22
Tegula fasciata^x (Born)	--	0.24	0.17	0.22
Turbo castaneus^x (Gmelin)	0.31	--	0.50	--
Vermicularia spirata^x Philippi	--	0.12	--	--
Lamellibranchia				
Anodontia alba Link	0.94	0.24	--	--
Antigona listeri (Gray)	--	--	0.17	--
Arcopsis adamsi^x (Smith)	--	0.36	--	--
Barbatia cancellaria^x (Lamarck)	--	0.12	--	--
B. domingensis^x (Lamarck)	--	0.12	--	--
Chione cancellata (Linne)	0.31	0.36	0.83	--
Codakia orbicularis (Linne)	--	0.24	0.17	--
C. portoricana (Dall)	0.31	1.21	--	--
Cyclinella tenuis (Recluz)	0.94	0.12	--	--
Dosinia elegans Conrad	0.31	0.12	--	--
Glycymeris pectinata (Gmelin)	--	0.12	0.83	0.67
Laevicardium laevigatum (Linne)	1.25	0.48	0.66	0.22
L. mortoni (Conrad)	--	1.82	--	--
Lima pellucida^x C. B. Adams)	1.25	--	--	--
Lucinia multilineata (Tuomey and Holmes)	--	0.36	0.33	--

Table 67 (Cont'd)

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Lamellibranchia				
Lucinia pensylvanica (Linne)	--	--	--	0.22
Modiolus americanus^x (Leach)	0.31	--	--	--
Nucula proxima Say	--	1.58	1.65	--
Pecten antillarum^x Recluz	--	--	--	0.44
P. nucleus^x (Born)	--	0.12	--	--
Pinctada radiata^x (Leach)	--	0.36	--	0.22
Pitar fulminata (Menke)	1.56	1.21	0.17	--
Quadrans lintea (Conrad)	0.31	--	--	--
Semele purpurascens (Gmelin)	--	--	--	0.22
Tagelus divisus (Spengler)	--	1.21	--	--
Trachycardium muricatum (Linne)	--	0.24	0.17	--
Tellina alternata Say	0.31	1.58	--	--
T. martinicensis d'Orbigny	--	0.61	--	--
T. similis Sowerby	1.88	1.09	0.33	0.22
T. versicolor Cozzens	5.94	1.45	0.83	--
Isopoda				
Cilicaea caudata^x (Say)	--	0.12	--	--
Rocinela signata^x Schioedte and Meinhart	--	--	0.17	--
Penaeidea				
Penaeus duorarum^x Burkenroad	0.31	0.24	--	--

Table 67 (Cont'd)

Species	<0.2 mm	0.2-0.4 mm	0.4-0.6 mm	>0.6 mm
Caridea				
Alpheus armillatus^{x} Milne Edwards	--	0.48	--	--
Anomura				
Paguristes tortugae^{x} Schmitt	--	0.61	--	--
Thalassinid sp.	--	0.12	--	--
Brachyura				
Callinectes sapidus^{o} Rathbun	--	0.12	--	--
Eucratopsis crassimanus^{o} (Dana)	0.94	0.48	0.33	--
Mithrax sp.^{x}	0.63	--	0.17	0.22
Microphrys bicornutus^{x} (Latreille)	--	--	--	0.22
Stomatopoda				
Gonodactylus oerstedi^{x} Hansen	--	0.12	--	--
Pseudosquilla ciliata^{o} (Fabricius)	--	--	0.33	0.22

Fouling

Ocean fouling in the Straits of Florida and Tongue of the Ocean (TOTO) has been studied by DePalma (1963, 1969). In a transect extending out to water depths of 150 meters at Ft. Lauderdale, DePalma found that diversity of species and mass of fouling diminished with depth and increasing distance from shore. (See figures 77 and 78, and table 68). The biofouling community off Ft Lauderdale is dominated by barnacles and the oysters, *Pinclada radiata* and *Ostrea frons*, which attach and grow rapidly throughout the year. Other groups found at depths we are considering include the tunicates, bryozoans, and tubeworms (see table 68). If wood is to be used, the severe crustacean and molluscan borer activity in this region must be taken into account.

Information on fouling in Biscayne Bay can be found in Joseph and Nichy (1955), Moore and Frue (1959), Isham et al (1951), and Werner (1967). Additional information on the biology of Tongue of the Ocean is given by Kral (1962).

Table 68. Biofoulers Collected from Florida Straits and TOTO (from DePalma, 1967)

Species	Site and Panel Number[+]
Algae	
Dilophus ahernans	B2,C2,E2,E3
Heterosiphonia sp.	C2,D2,E2,F2,F3,G2,G3
Spyridia sp.	C2,D2,E2,E3
Sargassum filipendula	B2,D2,E2,G2
Cladophora sp.	B2,C2,D2,E2,E3,F2,F3,G2
[illegible]naria variegata	C2,D2,E2
Jania sp.	B2,D2,E2
Gracilaria sp.	B2,C2,D2,E2
Padina vickersiae	B2,C2,C3,D2,D3,G2,G3
Ulva sp.	B2,C2,C3,D2,D3,E2,E3
Chrysonephos lewisii	B2,B3,C2,D2,E2,F2,F3,G3
Protozoa	
Trachammina compacta	F11,G14,G15
Homotrema rubrum	G5

[+] See figures 77 and 78.

Table 68 (Cont'd)

Species	Site and Panel Number+
Porifera	
Spongia officinalis	B2,B3,C2,D2
Grantia sp.	B2,B3,C2,C3,D2,D3,D4,E2
Coelenterata	
Tubulariidae	D5,E4,E5,E6,E7,F11,G14,G15
Sertulariidae	D5,F2,F3,F4,F5,F6,F7,G2,G3,G4, G5,G6,G7
Oculina diffusa	C3,F3,F5,G3,G4,G5
Acropora sp.	C3,F3,F4,G3,G4
Porites sp.	D3,F3,F4,F5,G3,G4,G5
Gorgoniidae	B2,C2,D2,D3,F2,G2
Companulariidae*	A1,B2,B3,C2,C3,C4,D2,D3,D4,D5,E2 E3,E4,E5,F2,F3,F4
Bryozoa	
Microporella trispinosa	B3
Harmerella dichotoma	B3
Schizoporella unicornis	A1,D4,D5
Parellisina latirostris	D5
Celleporella vagans	D5
Parasmittina spatularia	D5
Biflustra tenuis	E2
Bugula sp.	B3
Annelida	
Hydroides parvus	A1,B2,B3,C2,C3,C4,D2,D4,D5,E3,E4, E5
H. norvegica	B3,C4,F2,F3,F4,F5,G2,G3,G4,G5
Pomatoceros sp.	B3,C4,D4,D5,E4,F2,G2,G4
Vermiliopsis infundibulum	A1,F3,G3
Pomatostegus latiscapus	B3,E7,F3,F5,G3,G5

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*See figures 77 and 78.

*Dominant species, i.e., occupied more than 50 percent of surface on one or more test panels.

Table 68 (Cont'd)

Species	Site and Panel Number +
Annelida	
Serpula vermicularis	C2
Salmacina incrustans	A1, B2, B3, C4, D5, F4, G4
Serpulidae	G14, G15
Sabellidae	G14, G15
Arthropoda	
*Balanus improvisus**	A1, B2, B3, C3, D3, D4
*B. triganus**	A1, B2, B3, C2, C3, C4, D2, D3, D4, D5
B. tintinnabulum	B2, B3, C2, C3, C4, D3
B. eburneus	A1, B3, D2, D3
B. calidus	B3, C4, D3, D4
B. venustus nivens	A1, B3, C4
B. sp.	E3, E4, E5, F2
Heteralepas cornuta	C4, D4, D5
Conchoderma virgatum	D2, F2, F3, F4, G2, G3, G4
Scalpellum portoricanum	E7
Paecilasma inaequilaterale	E7
Lepas anatifera	D2, E2, F2, F3, F4, F5, F6, F7, G2, G3, G4, G5, G6, G7
Mollusca (Foulers)	
*Ostrea frons**	B2, B3, C2, C3, C4, D2, D3, E2, E3, F2, F3, F4, F5, G2, G3, G4, G5
*O. equestris**	B2, B3, C2, C3, C4, D2, D3, D4, E2, E3, F2, F3, F4, G2, G3, G4
*Pinctada radiata**	A1, B2, B3, C2, C3, C4, D2, E2, F2, F3, F4, G2, G3, G4
*Pycnodonta thomasi**	B2, B3, C2, C3, C4, D2, D4, D5, E3, E4, E5, F3, F4, F5, G4, G5
Pteria colymbus	B2, C3, C4, D3, D4, D5, E2, E3, E4, E5, F2, G2, G4

+See figures 77 and 78.

*Dominant species, i.e., occupied more than 50 percent of surface on one or more test panels.

Table 66 (Cont'd)

Species	Site and Panel Number +
Mollusca (Foulers)	
Anomia simplex*	A1,B2,B3,D2,E2,E3,F2,F3,F4,F5,G2,G3,G4,G5
Pinna carnea	B2,B3,C2,D2,F2,F3,F4,G3,G4
Crassostrea rhizophorae*	A1
Chama macrophylla*	B2,B3,C2,C3,D2,E2,F2,F3,F4,G2,G3 G4,G5
Arca zebra	B2,D2,E2,F3,G2,G3
Musculus lateralis	B2,C2,C3,C4,D2,E2,E3
Spondylus americanus*	B2,B3,D5,F2,F3,F4,F5,G2,G3,G4
Aequipecten muscosus	B2,B3,C2,C3,C4,F2,F3,F4,G3,G4
Brevimalleus condeanus	B2
Hiatella arctica	E2
Mollusca (Borers)	
Lyrodus pedicellatus	B2,B3,C2,C3,D2,D3
Teredo bartschi	B2,B3,C2,C3
T. clappi	B3
T. fulcifera	E2,E3,E4
T. fulleri	E4
T. navalis	E3
T. sp.	F2
Teredothyra matocotana	B2,B3,C2,C3,C4,D2,D3,D4
Teredora malleolus	D2,D3,D4,E2,E3,E4
Nototeredo knoxi	D3
Bankia gouldi	B2,D2
B. fosteri	C2,C4,D2,D4,E2,E4
B. carinata	B2,B3,C2,C3,C4,D2,D3,D4,D5,E2, E3,E4,E5,E6,E7

+See figures 77 and 78.

*Dominant species, i.e., occupied more than 50 percent of surface on one or more test panels.

Table 68 (Cont'd)

Species	Site and Panel Number +
Mollusca (Borers)(Cont'd)	
Xylophaga a	C3,C4,D3,D4,D5
X. b	E6,E7
X. c	E7
Xyloredo noli, Turner[1]	G15
Chordata (Tunicata)	
Botryllus sp.	B2,B3,C2,C3,D2,D3,D4
Styela sp.	A1,B2,B3,C2,C3,D2,D3,E3,F2,F4, G2,G3
Ciona intestinalis	A1,B2
Ascidia nigra	B2
Ascidiidae	C2

+See figures 77 and 78.

*Dominant species, i.e., occupied more than 50 percent of surface on one or more test panels.

[1] A new genus, presently being described by Dr. Ruth D. Turner.

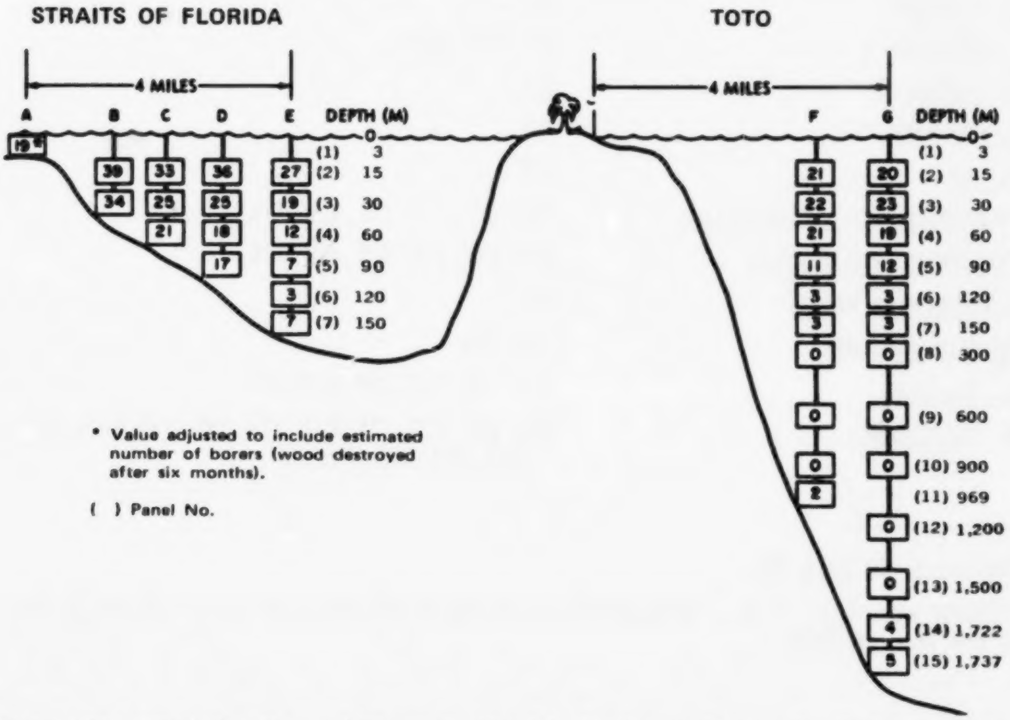
STRAITS OF FLORIDA
TOTO
4 MILES
4 MILES
A
B
C
D
E
F
G
DEPTH (M)
DEPTH (M)
0
(1) 3
(2) 15
(3) 30
(4) 60
(5) 90
(6) 120
(7) 150
(8) 300
(9) 600
(10) 900
(11) 969
(12) 1,200
(13) 1,500
(14) 1,722
(15) 1,737
19*
30
34
33
25
21
36
25
18
17
27
19
12
7
3
7
21
22
21
11
3
3
0
0
0
2
20
23
19
12
3
3
0
0
0
0
0
4
5
* Value adjusted to include estimated number of borers (wood destroyed after six months).
( ) Panel No.

Figure 77. Distribution of Taxa in the Study Area (from de Palma, 1969)

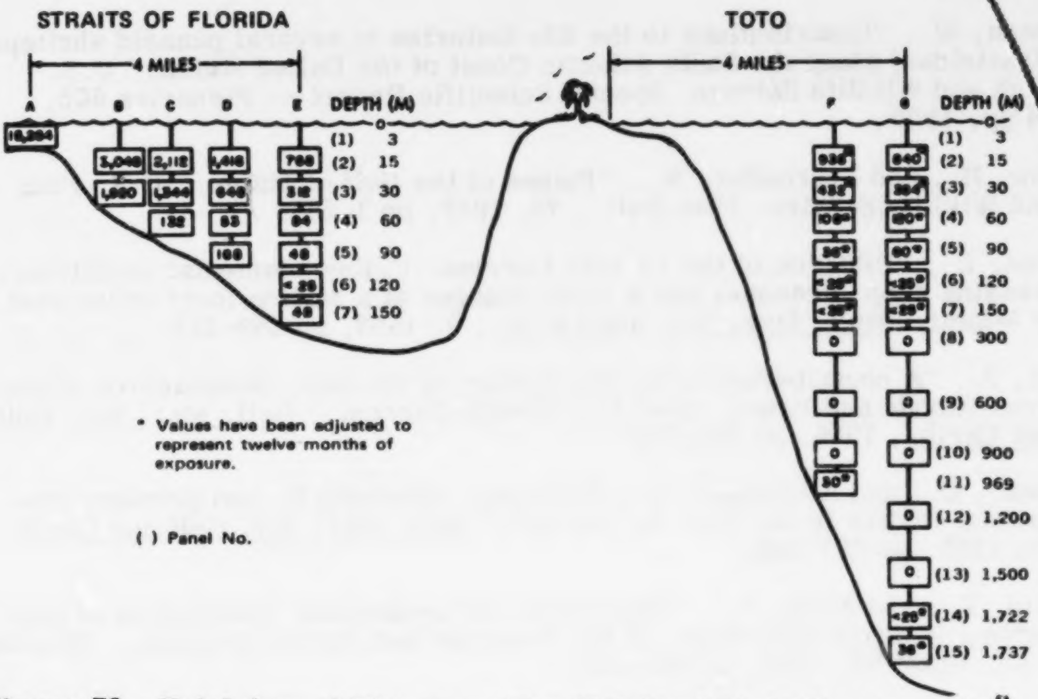
STRAITS OF FLORIDA
4 MILES
A
B
C
D
E
DEPTH (M)
0
(1) 3
(2) 15
(3) 30
(4) 60
(5) 90
(6) 120
(7) 150
10,204
5,040
2,112
1,416
768
1,920
1,344
648
312
132
83
84
108
48
< 25
48
* Values have been adjusted to represent twelve months of exposure.
( ) Panel No.
TOTO
4 MILES
F
G
DEPTH (M)
0
(1) 3
(2) 15
(3) 30
(4) 60
(5) 90
(6) 120
(7) 150
(8) 300
(9) 600
(10) 900
(11) 969
(12) 1,200
(13) 1,500
(14) 1,722
(15) 1,737
936*
432*
108*
36*
<25*
<25*
0
0
0
30*
840*
384*
180*
60*
<25*
<25*
0
0
0
0
0
<25*
36*

Figure 78. Total Annual Biomass: Dry Weight of Biofouling in gm/m^2 (from dePalma, 1969)

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Section 5

SITE DESCRIPTION FOR WATERS OFF SOUTHERN CALIFORNIA

PHYSICAL DESCRIPTION (SAN ONOFRE AREA)

Water Circulation and Characteristics

The sea off southern California (figure 79) lies in a "Mediterranean" climatic area of basically two seasons: summer is a warm, dry season, and winter is a mild, short season. The southern California shelf waters are subject to considerable mixing by wave action and currents. However, in summer the water column is well stratified, with the surface 8 to 11°C warmer than the 200-ft depth. In winter the stability of the water column is less (average gradient in the upper 200 ft about 3°C) and occasional high winds may result in nearly complete mixing with the gradient in the upper 200 ft as little as 1/2 to 1°C (The Allan Hancock Foundation, 1965).

Table 69 summarizes the means and extremes of temperature, salinity, and density for the site area, by season. Figure 80 shows the temperature envelopes for the area for winter and summer. It is evident that the major seasonal change in the water column occurs in the upper 60 ft. Salinity increases with depth over a narrow range and a salinity inversion may occur in summer near the surface due to evaporation (The Allan Hancock Foundation, 1965).

A feature of the mainland shelf thermal structure is the development and movement of "cold spots." These features are a product of vertical stirring in an area of highly stratified waters (the summer condition) as a result of raising cold subsurface water to the surface or near it. Tidal stirring can occur in areas of favorable bottom contours and as a consequence of the more intensive mixing that accompanies spring tides. The cold spots have a domelike shape and may have diameters up to 4 or 5 nm (The Allan Hancock Foundation, 1965). These cold spots appear to move either in response to tidal currents or as a result of fluctuating eddy intensity in response to variation in tidal amplitude.

In either case, movement occurs within a tidal period (Emery, 1960). On the basis of available data, it is uncertain whether cold spots are likely to occur in the San Onofre area.

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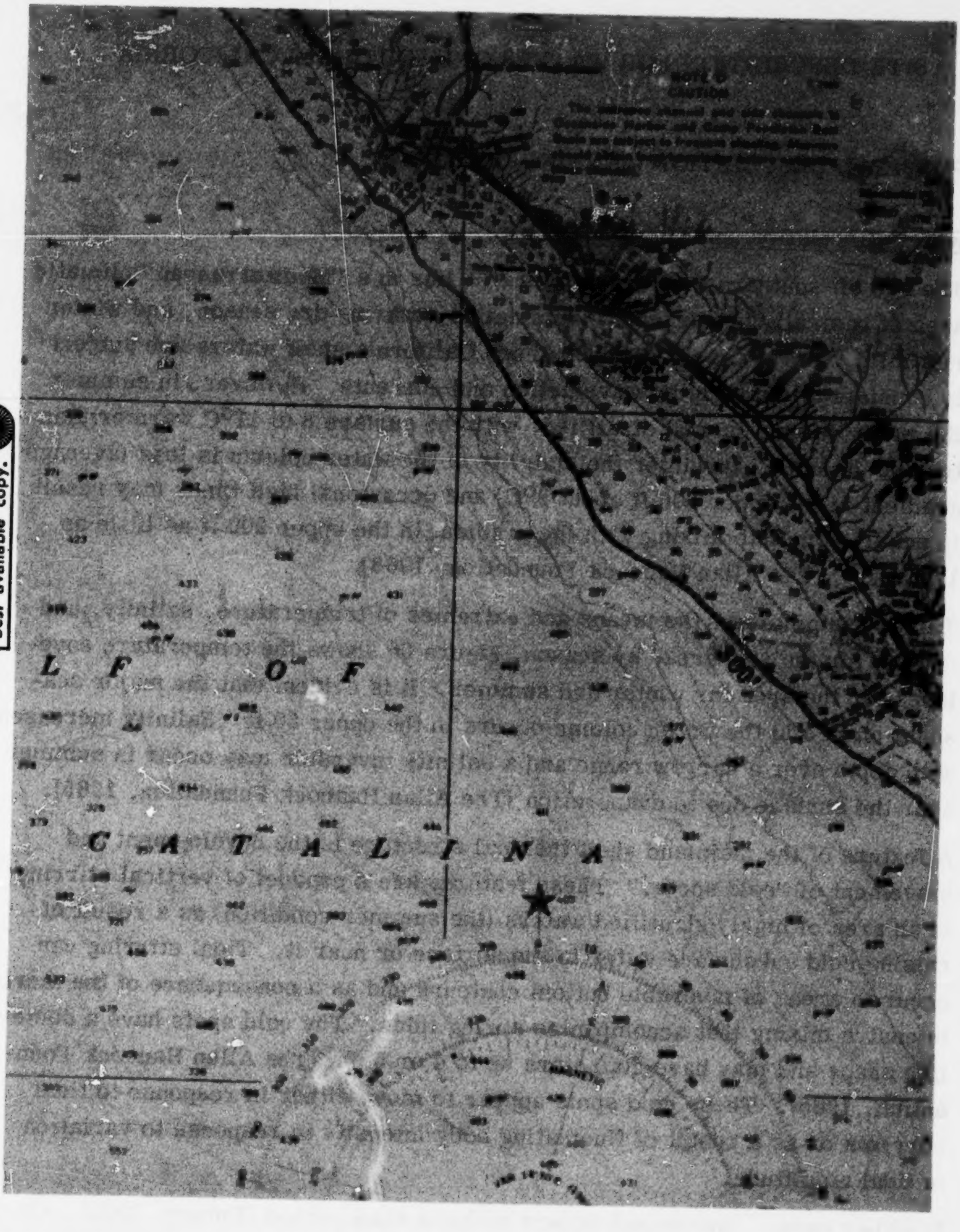

Figure 79. Soundings (Fathoms) of Area off San Onofre, Southern California (from Coast and Geodetic Survey Chart 5101)

Table 69. Temperature, Salinity, and Density Data* for the San Onofre Site

Depth (m)	Density (ρ_t)			Temperature (^{o}C)			Salinity ($^{o}/oo$)		
	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min
					Winter				
0	24.70	25.39	23.64	15.55	19.02	12.90	33.45	33.73	32.99
10	24.73	25.44	23.73	15.33	18.64	12.74	33.46	33.96	33.04
20	24.81	25.52	23.75	14.92	18.60	12.10	33.46	33.27	33.17
30	24.91	25.61	23.81	14.36	18.38	11.38	33.45	33.71	33.18
50	25.21	25.83	24.28	12.89	16.59	10.32	33.44	33.69	33.12
75	27.51	26.04	24.75	11.72	15.98	9.50	33.53	33.81	33.21
					Summer				
0	23.83	24.69	23.21	19.41	25.00	15.94	33.57	33.89	33.28
10	24.24	25.19	23.22	17.62	22.50	13.47	33.53	33.54	33.22
20	24.87	25.60	23.95	17.84	18.12	11.92	33.49	33.77	33.18
30	25.24	25.83	24.35	13.04	17.06	10.32	33.47	33.81	33.11
50	25.50	26.03	24.64	11.47	15.86	9.72	33.52	33.75	33.18
75	25.85	26.18	24.98	10.39	14.35	9.29	33.64	33.87	33.27

*Temperature is given in degrees Celsius, salinity in parts per thousand ($^{o}/oo$), and density in sigma-t units (where, e.g., 24.39 represents a specific gravity of 1.02439).

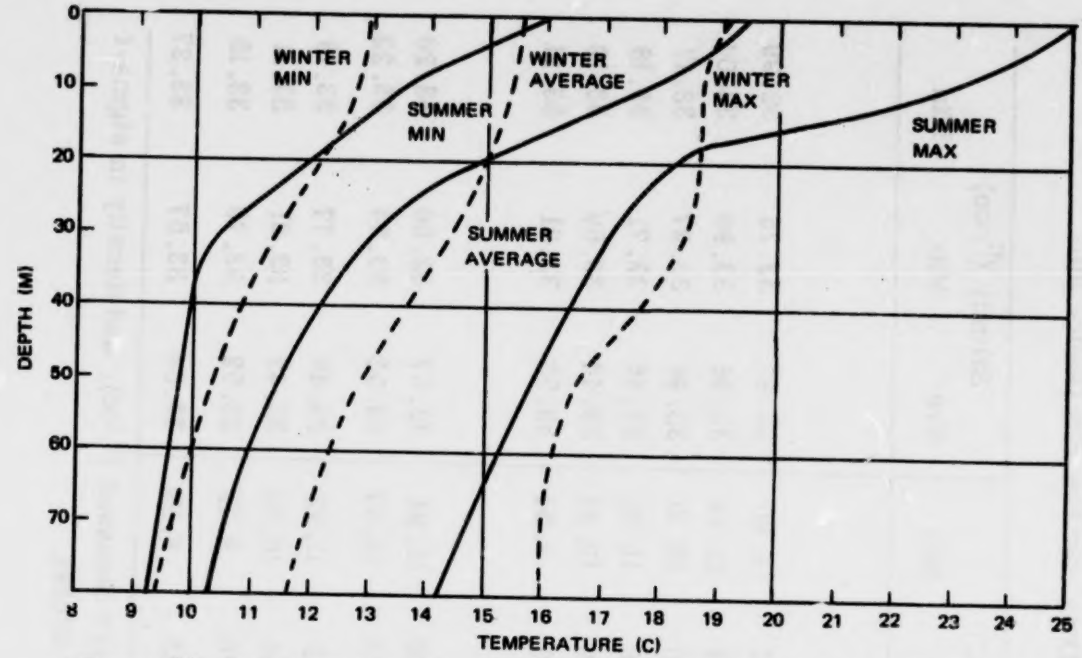

Figure 80. Temperature Profiles of Water at the San Onofre Site

The California Current is an extension of the Japanese Current that has been cooled and has had arctic water added during its passage across the North Pacific, past the Aleutians. This current flows southeasterly just off the coast of Washington, Oregon, and northern California. Due to the indentation of the southern California coastline, and to the Santa Rosa-Cortez ridge that extends southeast from Point Conception, the California current flows about 150 nm offshore of the southern California coast.

East of the California Current off southern California is a large cyclonic eddy with a period of 20 to 40 days (The Allan Hancock Foundation, 1965). This eddy circulation is complex, smaller eddys having been observed within the large gyre (Schwarzlose, 1963). The eddy apparently weakens in spring and, in some years, does not exist during that season. At such times a southeasterly drift occurs.

The waters of this eddy pattern are derived primarily from the California Current, but they become noticeably heated during their long residence in the eddy as well as by the entrainment of southern water. Shoreward of this eddy, on the continental shelf, the current flows to the southeast following the coast. On the southern California shelf, wind is the most dominant influence over the shelf currents (The Allan Hancock Foundation, 1965), and wide variations in shelf current directions and velocity are common. The net flow, however, is to the southeast.

Surface currents have velocities ranging from 0.1 to 0.4 kt, with rare examples of velocities up to 0.7 kt. Maximum velocity can occur at any depth, but most often at the surface, with the current speed at 50 ft averaging about one-half that at the surface. Current direction can change with depth and differ from the direction at the surface by as much as 180° (The Allan Hancock Foundation, 1965).

The relationship between wind and ocean currents has been previously discussed -- current velocity is about 2 to 3 percent of the wind velocity after steady state conditions are reached, in a direction more or less directly downwind, on an open shelf. Figure 81 shows the average annual winds off California. South of Santa Barbara Channel, the winds are from the west and northwest 64 percent of the time on an annual average (USN Weather Service Command, 1970), more or less parallel to the coast. The surface currents are generally to the southeast and flow with the wind. When the wind blows onshore, boundary effects cause the current to continue flowing southeast (Emery, 1960). Average wind velocities are 6-8 kt, resulting in predicted current velocities due to wind of 0.1-0.3 kt. Table 70 presents the annual frequency of wind directions and velocity. Wind velocities up to 27 kt occur nearly 12 percent of the time and could produce currents up to 0.8 kt, depending upon wind persistence. Because data in this table apply to an area extending as far as 120 nm offshore, mainland shelf conditions may be somewhat below the average given. In general, the drift of the surface water is offshore, resulting in cooler subsurface water rising next to the coast (The Allan Hancock Foundation, 1965).

The tidal wave off southern California moves from southeast to northwest, with tidal currents rarely exceeding 0.4 kt (Emery, 1960). For depths on the open shelf at the site location, current velocities would theoretically be less than 0.1 kt. Tidal currents close to shore parallel the shore and bottom contours, while rotary currents occur on the open shelf. The net flow is to the southeast.

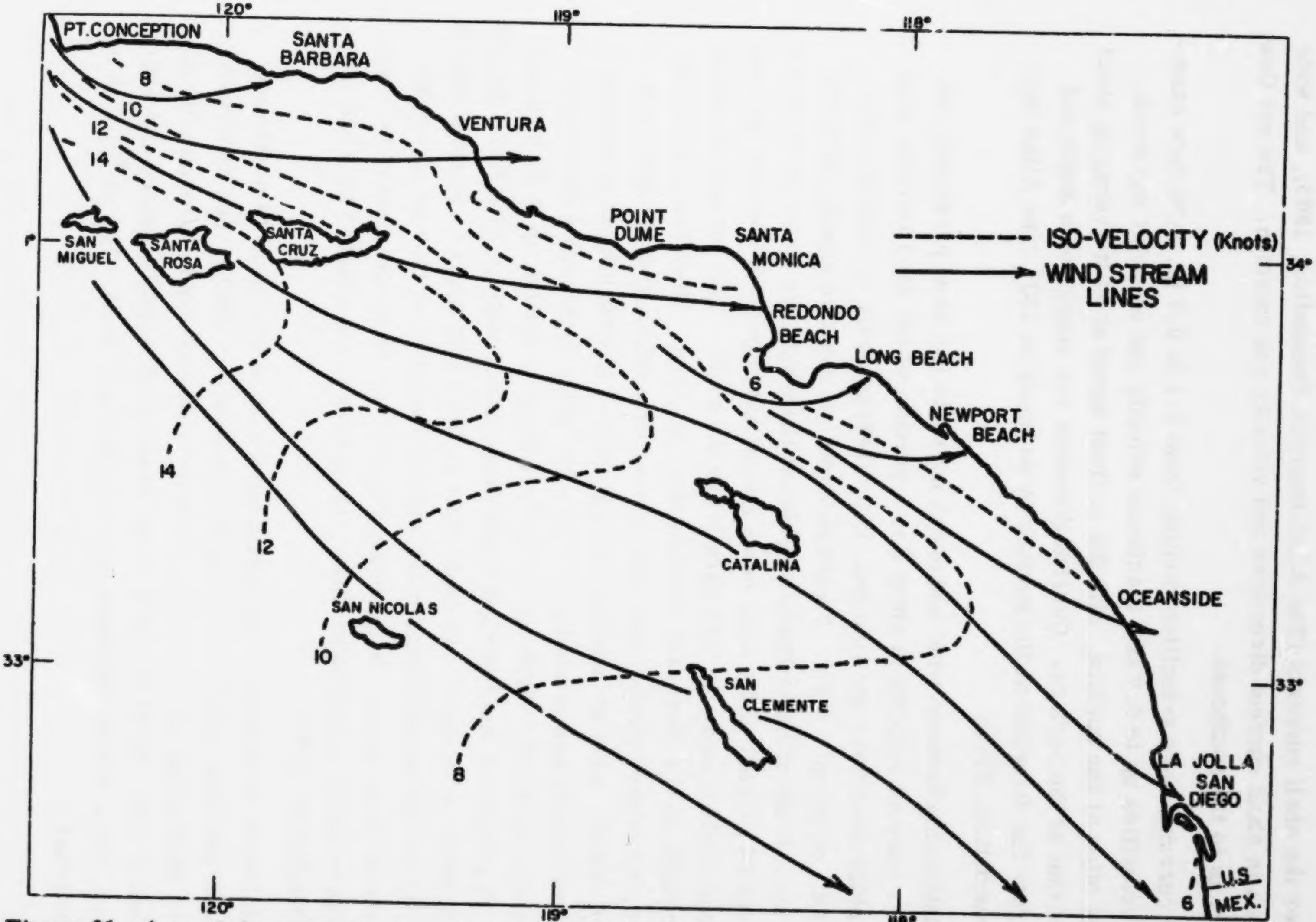
120°
119°
118°
34°
33°
PT. CONCEPTION
SANTA BARBARA
VENTURA
POINT DUME
SANTA MONICA
REDONDO BEACH
LONG BEACH
NEWPORT BEACH
OCEANSIDE
LA JOLLA
SAN DIEGO
U.S.
MEX.
SAN MIGUEL
SANTA ROSA
SANTA CRUZ
SAN NICOLAS
CATALINA
SAN CLEMENTE
ISO-VELOCITY (Knots)
WIND STREAM LINES
8
10
12
14
6

Figure 81. Annual Average Winds -- Velocity and Direction -- of Southern California Coastal Region (from the Allan Hancock Foundation, 1965)

Table 70. Frequency of Wind Direction by Speed -- Annual Percentage (from U.S.N. Weather Service Command, 1970)

Wind Direction	Wind Velocity (knots)					Number of Observations	Percentage of Frequency	Mean Speed
	0-6	7-16	17-27	28-40	41+			
N	3.0	3.6	0.4	*	0.0	5362	7.1	8.4
NE	1.6	1.3	0.2	*	*	2324	3.1	7.5
E	1.9	1.3	0.1	*	*	2609	3.4	7.1
SE	1.8	1.7	0.2	*	*	2849	3.7	7.9
S	2.8	2.4	0.3	*	*	4285	5.6	7.8
SW	3.7	4.0	0.4	*	*	6167	8.1	7.9
W	8.0	19.5	4.3	0.4	*	24510	32.2	10.8
NW	6.6	19.2	5.8	0.5	*	24450	32.1	11.8
Variable	*	0.0	0.0	0.0	0.0	23	*	2.2
Calm	4.6					3473	4.6	0.0
Number of Observations	26008	40309	8969	743	23	76052		9.7
Percentage	34.2	53.0	11.8	1.0	*	100.0	100.0	(mean total)

*Frequencies between 0.0 % and 0.05%

Bottom Characteristics

The width of the continental shelf off the San Onofre area averages between 2 and 4 nm. Sediments near shore are fine sands, becoming finer with increasing distance from shore, sediments on the outer shelf being silts. At the depth of the site area, sediments are silt with a typical median diameter of 0.04 mm (The Allan Hancock Foundation, 1965). Figure 82 describes sediment characteristics along the continental shelf between Newport and Mexico. The shelf sediments are primarily detritus derived from the land and brought to the shore by rivers, and from shoreline erosion. Rock outcropping is common, particularly where the topography is irregular (Emery, 1970). Sediment is mainly composed of quartz and feldspar. Submarine topography, waves, and currents are responsible for the subsequent distribution of material on the shelf. Off the San Onofre area, the sediments have a moderate organic content, indicated by a nitrogen content of 0.5-1.0 percent, and a low shell content of about 2.0 percent calcium carbonate (The Allan Hancock Foundation, 1965).

Engineering property measurements are not available for the San Onofre area. However, five samples taken on the open shelf off San Diego in sediments composed of silts and sandy silts gave vane shear strength values of 0.057-0.201 psi and bearing capacities of 0.45 and 0.859 psi (only two bearing capacities were calculated) for square footings at the sediment surface (Moore, 1962). Mainland shelf silts from further north on the California shelf showed bearing capacities as high as 2.0 psi.

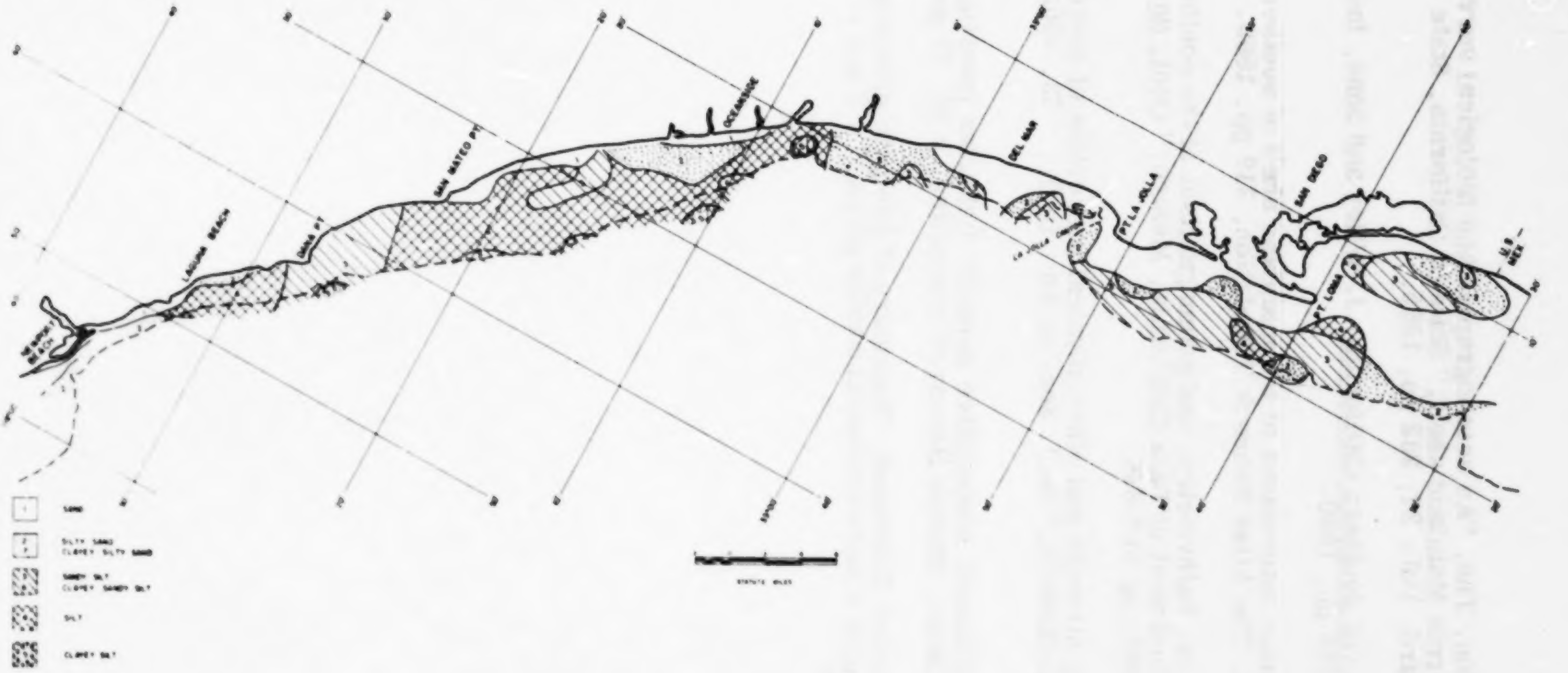
NEWPORT BEACH
LAGUNA BEACH
DANA PT
SAN MATEO PT
OCEANSIDE
DEL MAR
PT LA JOLLA
LA JOLLA CANYON
SAN DIEGO
PT LOMA
U.S.
MEX.
STATUTE MILES
SAND
SILTY SAND
CLAYEY SILTY SAND
SANDY SILT
CLAYEY SANDY SILT
SILT
CLAYEY SILT

Figure 82. Types of Sediment between Newport and Mexico
(from the Allan Hancock Foundation, 1965)

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Moore, D.G., "Bearing strength and other physical properties of some shallow and deep-sea sediments," Geol. Soc. of Am. Bull., 73, 1962, pp 1163-1166.

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BIOLOGICAL DESCRIPTION (SAN ONOFRE AREA)

Ecology

The ecology of the offshore waters in the San Onofre region of California has been systematically studied in broad outline for a great number of years. It is our impression that more is known about these offshore waters than about any coastal area in the United States, except perhaps the Gulf of Maine. This knowledge has been gained largely through the efforts of the Allan Hancock Foundation of the University of California, the California Cooperative Oceanic Fisheries Investigations (CalCOFI) organization, the Scripps Institute of Oceanography, and various California state agencies. The bibliography of Terry (1955) on marine geology and oceanography of the California coast is a useful introduction to the earlier literature, and Emery (1960) presents a fine systhesis of this information.

The unique and biologically important environmental features in this region are the relatively uniform moderate year-round water temperatures; the California current water circulation system and upwelling of nutrient-rich waters; the narrow shelf with deep water close to shore; a euphotic zone of about 50 meters; the frequent occurrence of dinoflagellate blooms termed "red tides;" and the presence of kelp beds. Biologically, these waters can be characterized generally by: (1) biota commonly composed of different biogeographic provinces, (2) high standing crops of plankton with the absence of the extreme seasonal pulses observed in the Gulf of Maine, and (3) high biological productivity.

As at the other locations surveyed the energy to support the offshore system is believed to be mainly generated offshore through the photosynthetic activities of pelagic phytoplankton ($\sim$500 gm/m^2/yr dry weight, Emery, 1960). The barren land and low rainfall of southern California suggest that nutrient contributions from land runoff is minimal, but major cities along the coast discharge large quantities of waste waters directly into the sea. Plankton productivity near these outfalls does not appear to be much greater than in areas distant from them. Except that different species play similar roles, this site appears to have no major differences from the other three sites in basic food relationships.

Phytoplankton

The species of phytoplankton found are independent of latitude from Point Conception to the Mexican border, due probably to the water circulation common to this general region (the Allan Hancock Foundation, 1965). Allen (1936) identified 100 species of phytoplankton representing 41 genera from daily samples collected over a 10-year period near Port Hueneme and La Jolla. The Allan Hancock Foundation (1965) identified 60 species of diatoms, representing more than 27 genera, and 11 species of dinoflagellates belonging to 12 genera, in 2,036 samples of shelf and oceanic waters. The species of diatoms most frequently observed by the foundation workers belonged to the genus *Chaetoceros* (also see Gunnerson and Emery, 1962); the most common dinoflagellate was *Prorocentrum micans* (also see Davis, 1955). Of the total plankton count, diatoms accounted for 54 percent, dinoflagellates 41 percent, and ciliates 2.6 percent. Miscellaneous groups made up the remainder.

A list of the diatoms found in the Allan Hancock Foundation studies, with their characteristic environments (as reported by Cupp, 1943) is given in table 71. The list shows that diatoms characteristic of many biogeographical provinces of the Pacific coast are represented at this site. No formal list of the dinoflagellates was presented, but data on all species sampled can be obtained from the foundation, if required. Other investigators list common dinoflagellates belonging to the genera *Prorocentrum*, *Ceratium*, and *Gonyaulax* in the southern California region (Gunnerson and Emery, 1962; Balech, 1960).

Seasonal abundance of phytoplankton is shown in table 72. The findings agree with those of such other workers as Bolin and Abbott (1963), and Abbott and Albee (1967) from studies further up the coast. The data show a peak abundance of diatoms in the late spring or early summer (~2000/L) and minimal abundance in the winter (~200/L). The actual numbers found varied widely, from sample to sample, both within a species and between different species.

The abundance of dinoflagellates (table 72) depends less on the season, but there is also some indication of greatest abundance during the summer. Numbers commonly ranged from 100/L to 700/L, and occasional samples contained as many as 2×10^6/L.

Table 71. Diatoms of the Coastal Waters of Southern California (from the Allan Hancock Foundation, 1965)

Species	Environment	Climate
Asterionella japonica	neritic	south temperate
Asteromphalus heptactis	oceanic	temperate
Bacteriastrum delicatulum	oceanic	temperate
B. hyalinum	neritic	widespread
Biddulphia longicruris	neritic	temperate - subtropical
B. mobiliensis	neritic	temperate - south temperate
Ceratulina bergonii	neritic	south temperate
Chaetoceros affinis	neritic	south temperate
C. compressus	neritic	boreal - south temperate
C. concavicornis	oceanic	boreal - arctic
C. convolutus	oceanic	arctic - boreal
C. costatus	neritic	tropical
C. curvisetus	neritic	south temperate
C. debilis	neritic	north temperate
C. decipiens	oceanic	arctic - boreal
C. didymus	neritic	south temperate
C. gracilis	neritic	widespread
C. laciniosus	neritic	south temperate
C. pendulus	oceanic	
C. peruvianus	oceanic	south temperate - tropical
C. socialis	neritic	north temperate
C. vanheurcki	neritic	
Coscinodiscus centralis pacifica	oceanic	temperate - north temperate
C. oculus iridis	oceanic	widespread
Coscinosira polychorda	neritic	north temperate
Dactyliosolen mediterraneus	neritic	widespread
Ditylum brightwellii	neritic	south temperate
Eucampia zoodiacus	neritic	south temperate

Table 71 (Continued)

Species	Environment	Climate
Fragiliaria crotenensis	neritic	north temperate boreal
Guinardia flaccida	neritic	south temperate
Hemiaulus hauckii	neritic and oceanic	temperate tropical
H. sinensis	neritic	south temperate - subtropical
Heptocylindrus danicus	neritic	north temperate
Licmophora abbreviata	littoral	widespread
Lithodesmium undulatum	neritic	south temperate
Navicula distans	littoral	
Nitzschia closterium	littoral	widespread
N. pungens var. atlantica	neritic	temperate
Pseudoeunotia doliolus	neritic and littoral	warm seas
Rhizosolenia alata	oceanic	temperate
R. castracanei	oceanic	tropical
R. delicatula	neritic	temperate
R. robusta	oceanic	warm seas
R. stolterfothii	neritic	widespread
R. styliformis	oceanic	north temperate
Schroderella delicatula	neritic	
Skeletonema costatum	neritic	widespread
Stephanophyxis turris	neritic	temperate and subtropical
Thalassionema nitzochiodes	neritic	north temperate
Thalassiosira aestivalis	neritic	
T. decipiens	neritic	north temperate
T. rotula	neritic	temperate and south temperate
Thalassiothrix mediterranea	neritic	temperate and south temperate
Tropidoneis antarctica polyplasta	littoral and neritic	

Table 72. Monthly Variation of Microplankton in Southern California Marine Waters (from the Allan Hancock Foundation, 1965)

	Bacillariophyceae (Diatoms)		Mastigophora (Dinoflagellates)	
Month	Medium Number per Liter	Percentage of Samples over 5000/L	Medium Number per Liter	Percentage of Samples over 2000/L
January	265	0	110	0
February	1650	0	245	13
March	590	2	145	1
April	1080	26	85	2
May	870	19	670	28
June	2550	21	386	8
July	1850	15	190	42
August	650	3	195	9
September	480	21	210	1
October	186	2	125	5
November	930	2	220	4
December	165	1	245	3

When dinoflagellates, such as species of Gonyaulax, attain abundance levels higher than about 50,000/L, "bloom" conditions are said to exist and a phenomenon termed "red tide" develops. Although these organisms are not visible to the naked eye, the light absorption of large numbers of dinoflagellates make the water appear reddish. The causes of red tide are not well understood, but are thought to be associated with the appearance of nutrients, normally deficient, in amounts large enough to produce the bloom conditions. Fish kills have been observed in Florida under such conditions. Edible shellfish often become toxic to humans after feeding on certain dinoflagellates, although the shellfish themselves suffer no apparent harm. Red tides occur more often as you go south from Point Conception to the Mexican border.

When averaged over long periods of time, the number of phytoplankton in oceanic (~100 miles offshore) and shelf waters off southern California are comparable (Allen, 1945a). Neritic waters, however, often contain larger numbers of phytoplankton than oceanic waters.

The diatom samples taken at about 25-ft depth intervals were examined and compared in the Allan Hancock Foundation studies. Counts at 0-50 ft were similar to but greater than those at 100-150 ft. Counts at depths greater than 100-150 ft were less than those at 100-150 ft. In contrast to the diatoms, dinoflagellates were most abundant at depths of 0-25 ft, while at 50 ft counts were about half as large. Allen (1928) observed the greatest numbers of phytoplankton at 30-60 ft in shallow water and at 60-90 ft in deeper, coastal waters. Dinoflagellates are motile and exhibit diurnal vertical movement, according to foundation investigators.

Under oceanic conditions, the maximum numbers of phytoplankton were observed at depths of 100-200 ft (Allen, 1945b). This difference is attributed to the greater clarity of oceanic waters as compared with coastal waters (the Allan Hancock Foundation, 1965; Emery, 1960).

Zooplankton

The zooplankton off California have been monitored by the CalCOFI organization in a series of oceanographic cruises begun in 1949. Results of these cruises are published in a series of reports and comprehensive atlases (CalCOFI Atlas No. 2, 3, 5, 6, 7, 8, and 10 ; these publications listed in bibliography by author).

The zooplankton found in 140-m oblique tows (0.5-mm mesh mets) were divided into about 17 functional groups by Isaacs et al (1969). Over the entire area that was sampled during these cruises, the following five groups made up more than 75 percent of the zooplankton population:

1. Copepoda
2. Thaliacea
3. Euphausiacea
4. Siphonophora
5. Chaetognatha

Euphausiacea, Siphonophora, and Chaetognatha generally made up less than 20 percent of the zooplankton; Copepoda and Thaliacea were the dominant groups. A list of the 17 functional groups of zooplankton and representative quantities from a few cruises are given in table 73 (Isaacs et al, 1969).

Data on abundance and seasonal occurrence of dominant zooplankton in the immediate vicinity of the San Onofre region are presented in table 74, listed in relative order of abundance in the spring. Although winter and summer cruises were also made, the data have not yet been published. The data show that zooplankton in general are more abundant in the spring than in the fall. Copepoda and Siphonophora appear to be more abundant in the spring and Euphausiacea in the fall. Chaetognatha and Thaliacea appear equally abundant in the spring and fall. The biomass of all zooplankton taxa ranged (in wet weight) from 16 to 256 gm/1000 m^3 in the spring and from 4 to 64 gm/ 1000 m^3 in the fall. When the San Onofre data are compared with the total area sampled, the Chaetognatha replace the Thaliacea in order of abundance; otherwise, the dominant groups are identical.

In an oceanographic survey of the northeast Pacific, Owens (1963) reported that Thaliacea, Chaetognatha, and Copepoda were the dominant zooplankton observed in plankton hauls. The seasonal distribution of zooplankton north and south of Point Conception is given in figure 83. Point Conception is accepted as marking the division between the two large biological provinces along the California coast. The solid line in the figure represents the separation of the productive inshore waters from those less productive offshore.

Table 73. Zooplankton of the Offshore California Waters (from Isaacs et al, 1969)

	Percentage of Total			Weight (gm/1000 m^3)			
Cruise No.*	5504	5510	5604	5504	5510	5604	Accumulated Weight
Amphipoda	0.7	2.0	0.4	98	210	133	441
Chaetognatha	4.0	10.0	4.0	575	1,180	1,267	3,022
Cladocera	<0.1	0.0	<0.1	0.6	0.03	0.1	0.73
Copepoda	42.0	39.0	26.0	5,297	4,799	8,330	18,426
Crustacean larvae	0.4	0.6	0.1	52	75	36	163
Ctenophora	0.6	5.0	0.7	88	653	225	966
Decapoda	3.0	0.6	4.0	440	72	1,271	1,783
Euphausiacea	8.0	6.0	8.0	1,010	698	2,588	4,296
Heteropoda	0.1	0.1	0.1	15	15	45	75
Larvacea	0.1	0.1	0.1	14	17	37	68
Medusae	2.0	2.0	3.0	200	210	819	1,229
Mysidacea	<0.1	<0.1	0.1	0.7	0.7	37	38.4
Ostracoda	0.2	0.2	0.1	28	29	45	102
Pteropoda	<0.1	2.0	<0.1	10	228	25	263
Radiolaria	0.3	5.0	0.6	51	663	202	916
Spinonophora	4.0	7.0	7.0	563	895	2,342	3,800
Thaliacea	34.0	21.0	45.0	4,357	2,598	14,260	21,215

*5504 = April 1955; 5510 = October 1955; 5604 = April 1956

Table 74. Biomass of Dominant Zooplankton in the San Onofre Region of California (adapted from Isaacs et al, 1969)

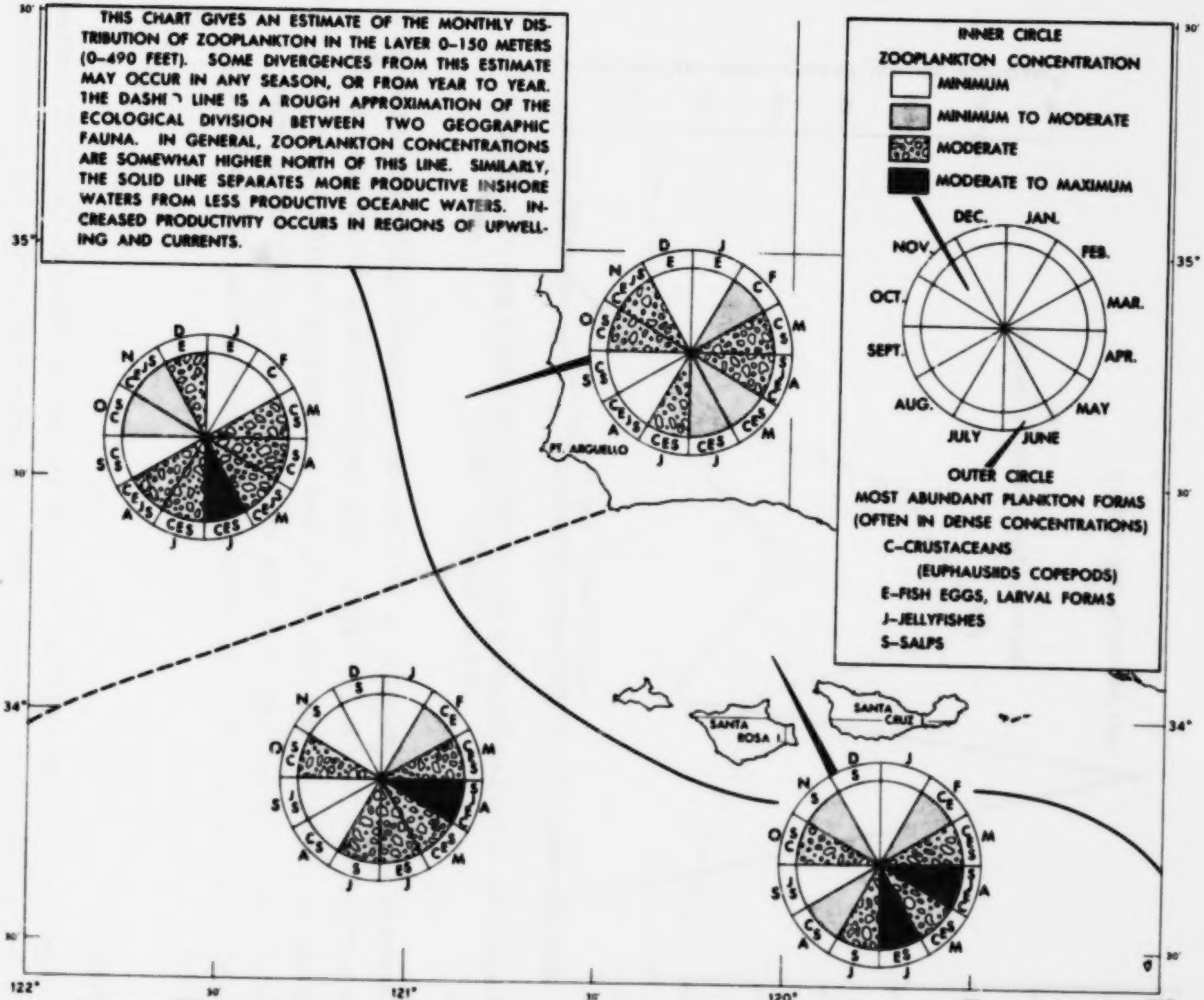
Mean Weight* g/1000 m^3	Spring Cruises					Fall Cruises				
	5504	5604	5704	5804	5904	5510	5610	5710	5810	5910
					All Taxa					
0										
1										
4										
16									X	
64		X			X	X	X	X		X
256	X		X	X						
					Copepoda					
0										
1										
4									X	X
16						X	X	X		
64	X	X	X	X	X					
					Chaetognatha					
0										
0.25						X				
1		X								X
4	X				X			X	X	
16				X						
64			X				X			
					Euphausiacea					
0										
0.25										
1		X								
4	X				X			X		
16			X	X		X	X		X	X

*wet weight

Table 74 (Continued)

Mean Weight* g/1000 m^3	Spring Cruises					Fall Cruises				
	5504	5604	5704	5804	5904	5510	5610	5710	5810	5910
					Siphonophora					
0										
0.25						X			X	
1			X					X		X
4	X	X			X		X			
16				X						
					Thaliacea					
0										
1		X		X	X	X	X		X	X
4	X							X		
16			X							

*wet weight



THIS CHART GIVES AN ESTIMATE OF THE MONTHLY DISTRIBUTION OF ZOOPLANKTON IN THE LAYER 0–150 METERS (0–490 FEET). SOME DIVERGENCES FROM THIS ESTIMATE MAY OCCUR IN ANY SEASON, OR FROM YEAR TO YEAR. THE DASHED LINE IS A ROUGH APPROXIMATION OF THE ECOLOGICAL DIVISION BETWEEN TWO GEOGRAPHIC FAUNA. IN GENERAL, ZOOPLANKTON CONCENTRATIONS ARE SOMEWHAT HIGHER NORTH OF THIS LINE. SIMILARLY, THE SOLID LINE SEPARATES MORE PRODUCTIVE INSHORE WATERS FROM LESS PRODUCTIVE OCEANIC WATERS. INCREASED PRODUCTIVITY OCCURS IN REGIONS OF UPWELLING AND CURRENTS.

INNER CIRCLE
ZOOPLANKTON CONCENTRATION
MINIMUM
MINIMUM TO MODERATE
MODERATE
MODERATE TO MAXIMUM
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
OUTER CIRCLE
MOST ABUNDANT PLANKTON FORMS
(OFTEN IN DENSE CONCENTRATIONS)
C–CRUSTACEANS
(EUPHAUSIIDS COPEPODS)
E–FISH EGGS, LARVAL FORMS
J–JELLYFISHES
S–SALPS
PT. ARGUELLO
SANTA ROSA I.
SANTA CRUZ
35°
34°
30'
122°
121°
120°
119°

Figure 83. Zooplankton Distribution for the Coastal Vicinity of Point Arguello (from USN Oceanographic Office, 1965)

As at the Maine and New York sites, the winter months appear to be the least productive periods. The zooplankton seasonal peak abundance occurs in June (also see figure 84, Emery, 1960) following the phytoplankton peak of early spring.

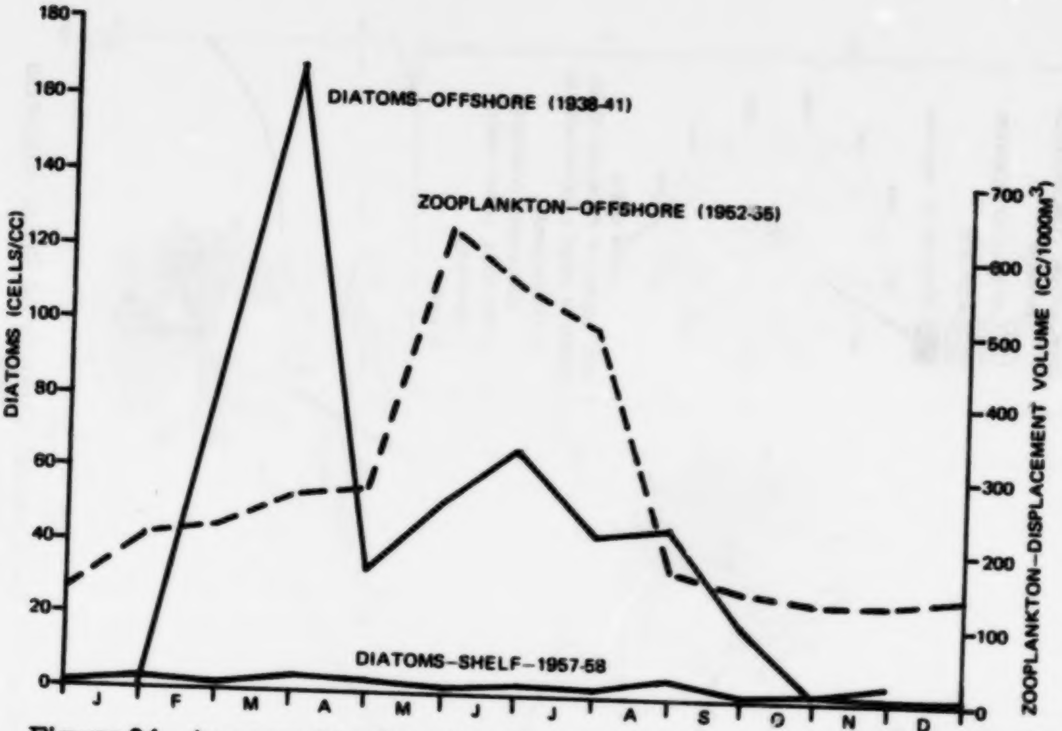


Figure 84. Average Monthly Abundance of Diatoms and Zooplankton (from Emery, 1960)

The average plankton volumes in 1960 for the southern California region are given in figure 85 (Thrailkill, 1969). The data show that the largest productive area occurred off San Francisco, and a smaller productive area occurred off San Diego, with plankton volumes exceeding 900 cc/1000 m^3 of water. The plankton volume of the San Onofre region ranged from 100 to 300 cc/1000 m^3.

Copepods

The common copepods and their relative abundance found in CalCOFI cruises are listed in table 75 (Fleminger, 1967). *Calanus tenuicornis* and *Ctenocalanus*

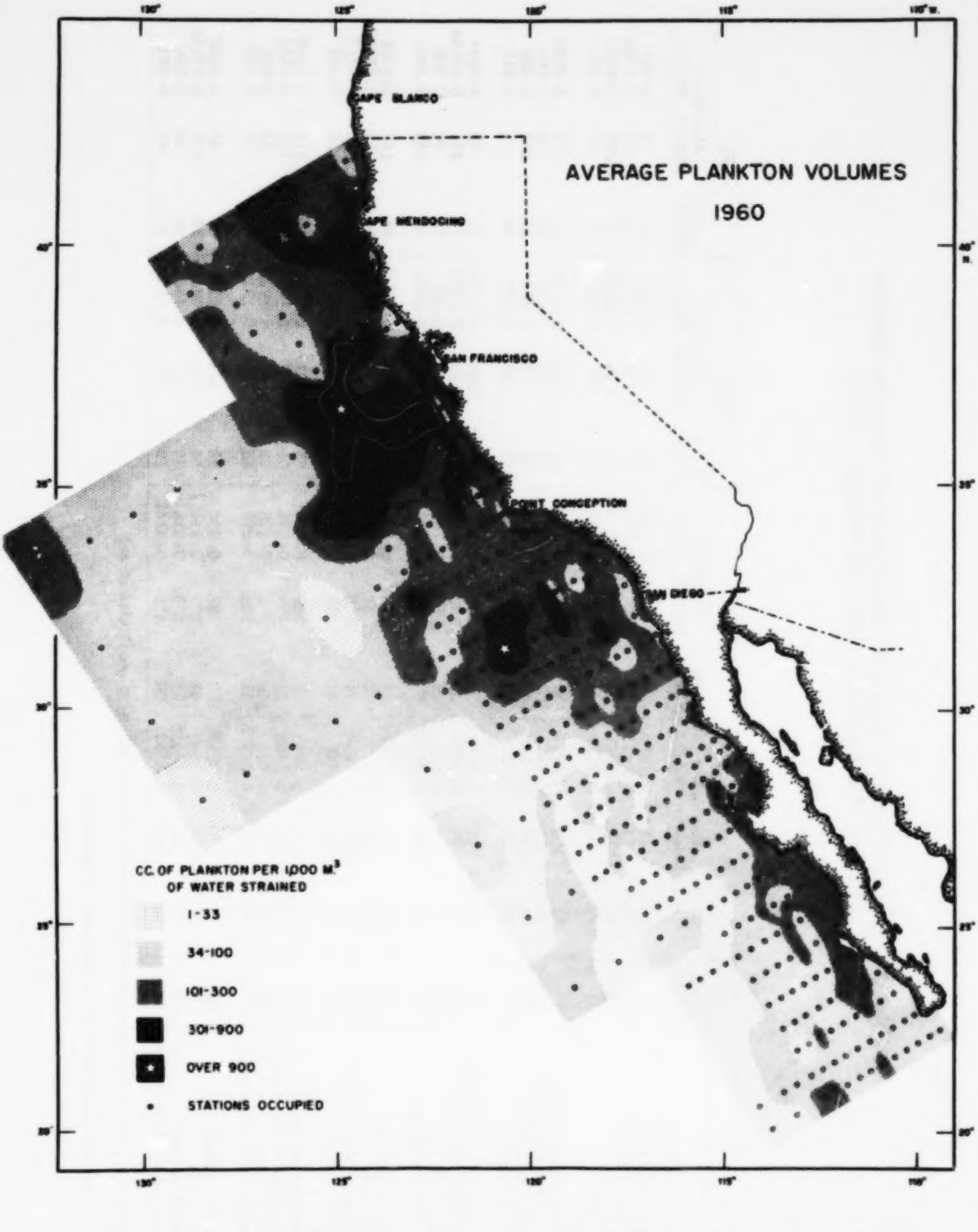

AVERAGE PLANKTON VOLUMES
1960
CAPE BLANCO
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
CC. OF PLANKTON PER 1,000 M.³ OF WATER STRAINED
1-33
34-100
101-300
301-900
OVER 900
STATIONS OCCUPIED
130°
125°
120°
115°
110° W.
40° N.
35°
30°
25°
20°

Figure 85. Average Plankton Volumes -- 1960 (from Thrailkill, 1969)

Table 75. Occurrence and Relative Abundance of Common Species of Copepods (Adults Only) (from Fleminger, 1967)

Cruise	All	5804			5807			5810			5901		
Species	%Occ. (154) #	%Occ. (43) #	Abundance Median	Abundance Range	%Occ. (35) #	Abundance Median	Abundance Range	%Occ. (37) #	Abundance Median	Abundance Range	%Occ. (39) #	Abundance Median	Abundance Range
Calanus tenuicornis	94	100	210	1-1048	94	200	0-1289	92	62	0-815	87	53	0-491
Ctenocalanus vanus*	92	95	137	0-1170	97	170	0-2469	89	79	0-677	85	105	0-1792
Calanus minor	78	88	135	0-1761	54	124	0-1656	92	365	0-1279	77	224	0-3362
Acartia danae*	78	86	68	0-2419	74	201	0-899	84	61	0-582	67	27	0-135
Clausocalanus furcatus*	77	81	264	0-3797	54	304	0-2506	81	348	0-1289	87	319	0-1646
Heterorhabdus papilliger	74	84	71	0-390	63	43	0-394	73	62	0-512	74	75	0-268
Pleuromamma gracilis	74	74	107	0-1605	49	115	0-686	89	77	0-627	82	102	0-528
Candacia bipinnata	71	84	84	0-595	66	22	0-602	78	63	0-368	54	1	0-213
Pleuromamma abdominalis	70	65	141	0-1156	54	194	0-1723	76	245	0-1721	85	72	0-2354
Pleuromamma borealis	70	74	279	0-8404	63	399	0-3780	62	360	0-3733	77	421	0-10164
Mecynocera clausi*	68	72	48	0-428	49	17	0-245	76	69	0-262	74	58	0-216
Calanus helgolandicus	67	70	388	0-29891	63	206	0-97483	62	161	0-4209	72	349	0-5552
Paracalanus parvus*	67	56	68	0-1599	74	485	0-17260	60	68	0-1504	80	192	0-2361
Candacia curta	66	67	54	0-1476	46	38	0-1642	76	36	0-1351	74	36	0-376
Clausocalanus pergens 1*	64	81	107	0-1558	71	118	0-2991	57	44	0-1053	46	40	0-1419
Lucicutia flavicornis	62	84	54	0-378	51	42	0-309	54	62	0-247	56	39	0-162
Clausocalanus farrani 1*	62	51	252	0-4249	46	458	0-7551	73	603	0-9025	80	619	0-5510
Clausocalanus arcuicornis 1*	59	72	123	0-5400	31	259	0-825	65	191	0-1463	64	151	0-3920
Scolecithrix danae	58	58	23	0-520	40	1	0-176	78	42	0-990	56	28	0-248
Clausocalanus arcuicornis 2*	57	79	115	0-916	63	105	0-570	43	82	0-191	41	75	0-752
Temora discaudata	50	46	72	0-7335	37	93	0-530	54	269	0-8903	62	45	0-1490
Metridia lucens	49	51	277	0-3600	54	276	0-33499	54	285	0-44659	38	523	0-15136
Rhincalanus nasutus	46	74	95	0-11436	43	135	0-838	27	21	0-486	36	19	0-554
Eucalanus bungii californicus	43	63	137	0-6246	54	416	0-6381	19	121	0-1389	33	41	0-587

*Abundance likely to be underestimated because size small relative to mesh size of net.

%Occ. = percent occurrence; ( ) = number of stations

vanus were the most common, and were found at nearly all of the stations sampled. Examination of CalCOFI Atlas No. 2 reveals that *Calanus helgolandicus*, *Pleuromamma borealis*, and *Metridia lucens* were the most abundant forms in the vicinity of San Onofre, ranging in number from 500 to 5000/1000 m^3 of water. As an example, the distribution of *Calanus helgolandicus* in the spring of 1958 is shown in figure 86.

The biogeographic habitat of copepods found in the California Current region are shown in table 76 (Fleminger, 1967). The table emphasizes the heterogeneity of the zooplankton in the region. The species making up the population are diverse, coming from inshore, offshore, arctic, and equatorial influences. The most abundance species in the vicinity of San Onofre, however, are classified as transitional species.

Esterly (1912, 1928) has studied the vertical distribution of copepods in southern California.

Chaetognaths

The distribution of Chaetognatha (Alvarino, 1965) in the California Current region can be found in CalCOFI Atlas No. 3. We were unable to review this study in time for this report; however, studies on Chaetognatha in northern California waters are discussed. Some overlap with southern California waters probably exists. Six species of Chaetognatha were identified: *Sagitta euneritica*, *S. scrippsae*, *S. decipiens*, *S. bierii*, *Eukrohnia hamata*, and *Krohnitta subtilis* (Allen, 1964). *S. euneritica* was the predominate species, making up approximately 85 percent of the worms collected. Allen (1964) indicated that arrow worms were highly stratified. The greatest concentrations were found at a 20-meter depth. Above and below this depth, densities were less. The distribution of arrow worms ranged from 0.6 to 0.8/m^3 (surface), 14.7 to 24.2/m^3 (20 meters), and 0.8 to 2.1/m^3 (30 meters). Summer, fall, and early winter samples contained the largest mean counts, while the least mean counts were obtained in late winter and early spring.

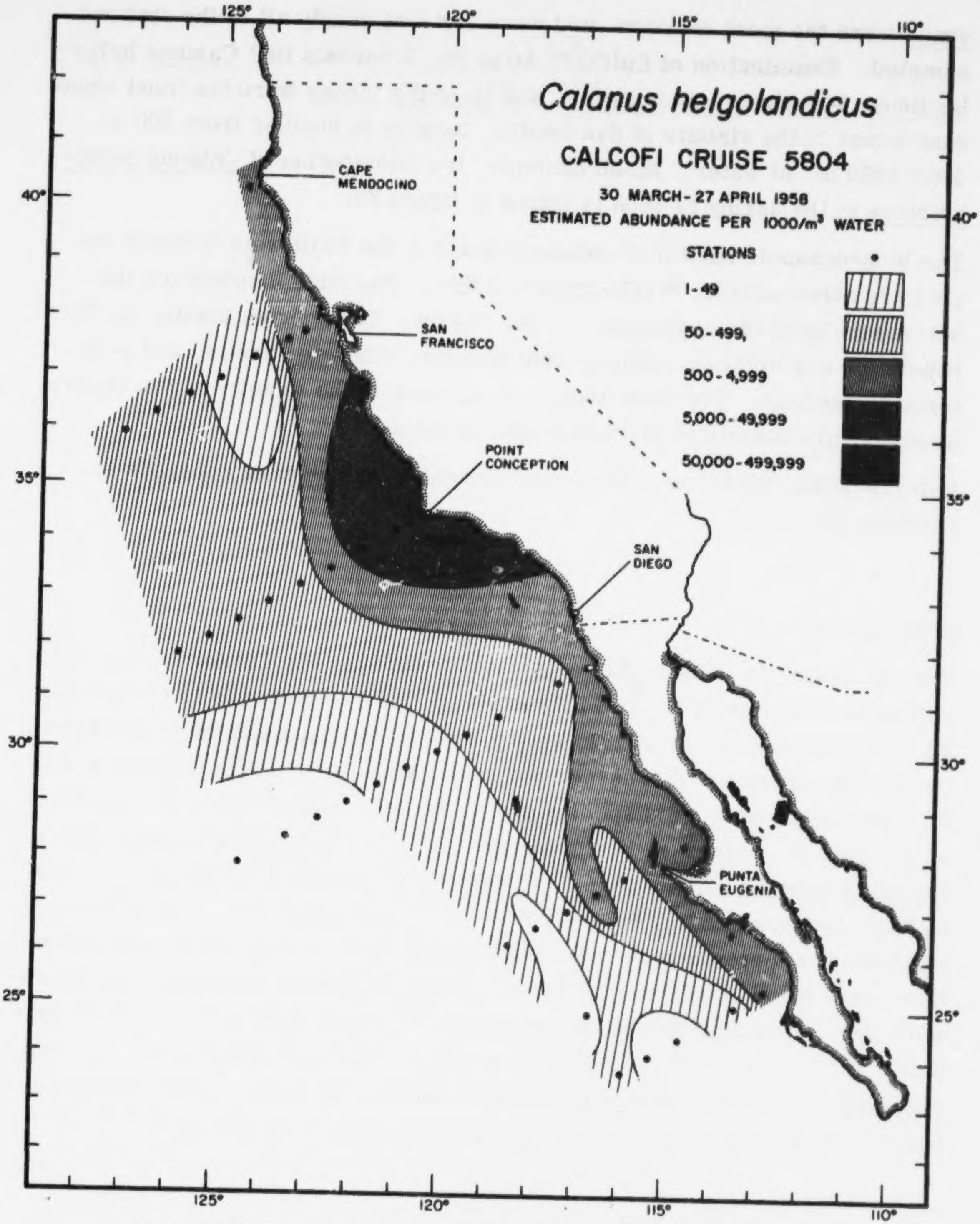

Calanus helgolandicus
CALCOFI CRUISE 5804
30 MARCH - 27 APRIL 1958
ESTIMATED ABUNDANCE PER 1000/m³ WATER
STATIONS
1-49
50-499,
500-4,999
5,000-49,999
50,000-499,999
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°

Figure 86. Estimated Abundance of Calanus helgolandicus (from Fleminger, 1967)

Table 76. Calanoid Copepods in the California Current Region (from Fleminger, 1967)

Subarctic Species
- *Calanus cristatus*
- *C. plumchrus*
- *Scolecithricella minor*

Transitional Species
- *Calanus helgolandicus*
- *Eucalanus bungii californicus*
- *Candacia bipinnata*
- *Rhincalanus nasutus*
- *Pleuromamma borealis*
- *Metridia lucens*
- *Clausocalanus pergens* 2
- *Heterorhabdus tanneri*
- *Racovitzanus antarcticus*
- *Scolecithricella ovata*

Central Species
- *Calanus gracilis*
- *Clausocalanus arcuicornis* 2
- *C. farrani* 2
- *C. paululus*
- *Euchaeta media*
- *Mecynocera clausi*
- *Centropages violaceus*
- *C. elegans*
- *C. elongatus*
- *Pleuromamma xiphias*
- *Paracandacia bispinosa*
- *P. simplex*
- *Eucalanus elongatus hyalinus*

Equatorial Oceanic Species
- *Scolecithricella abyssalis*
- *Euchaeta acuta*
- *E. longicornis*
- *Clausocalanus minor*
- *Eucalanus inermis*
- *Centropages gracilis*
- *Paracandacia truncata*
- *Candacia pofi*

Coastal-Neritic Species
- Endemics
  - *Labidocera trispinosa*
  - *L. jollae*
  - *Pontellopsis occidentalis*

Table 76 (Continued)

- Non-endemics (boreal-temperate)
  - *Acartia clausi*
  - *Tortanus discaudatus*
  - *Epilabidocera longipedata*
- Non-endemics (temperate-subtropical)
  - *Acartia tonsa*
  - *Paracalanus parvus*
  - *Temora discaudata*
  - *Clausocalanus farrani* 1
  - *Candacia curta*
- Non-endemics (tropical)
  - *Acartia lilljeborgi*
  - *Euchaeta wolfendini*
  - *Centropages furcatus*
  - *Candacia catula*
  - *Eucalanus pileatus*
  - *Labidocera actua*

Thaliacea

The abundance and distribution of two species of pelagic tunicates, *Doliolum denticulatum* and *Dolioletta gegenbauri*, are shown in figures 87 and 88 (Berner, 1967). The former species appears to be more southerly oriented than the latter. These two species have been used as indicators of water masses (figures 89 and 90), *Dolioletta gegenbauri* representing cool, sub-arctic or California Current waters while *Doliolum denticulatum* represents the warm central or subtropical waters (Berner, 196). The Thaliacea occur in the upper 100 m of water; highest concentrations are found in the upper 50 m.

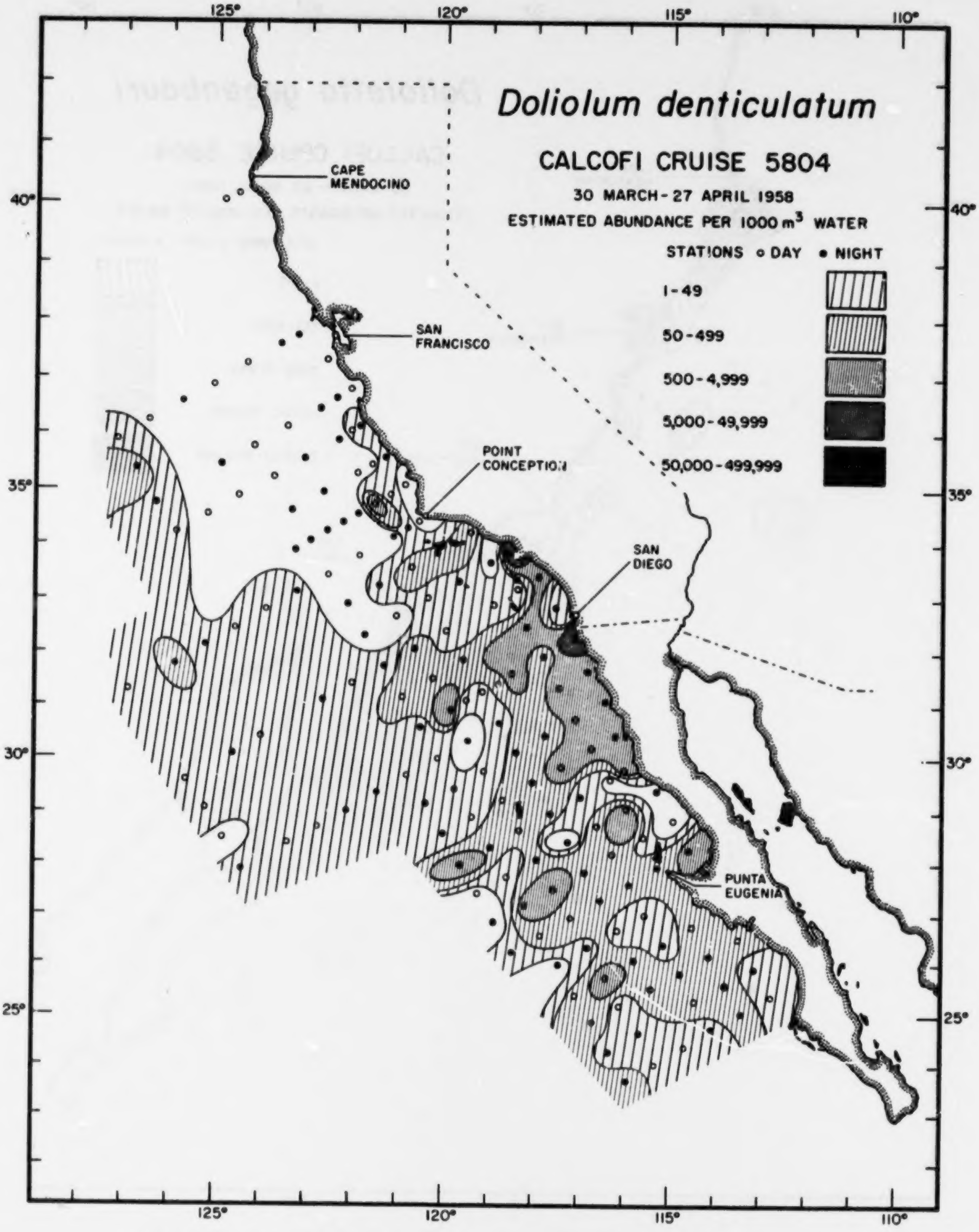

Doliolum denticulatum
CALCOFI CRUISE 5804
30 MARCH-27 APRIL 1958
ESTIMATED ABUNDANCE PER 1000 m³ WATER
STATIONS ○ DAY ● NIGHT
1-49
50-499
500-4,999
5,000-49,999
50,000-499,999
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°

Figure 87. Estimated Abundance of Doliolum denticulatum (from Berner, 1967)

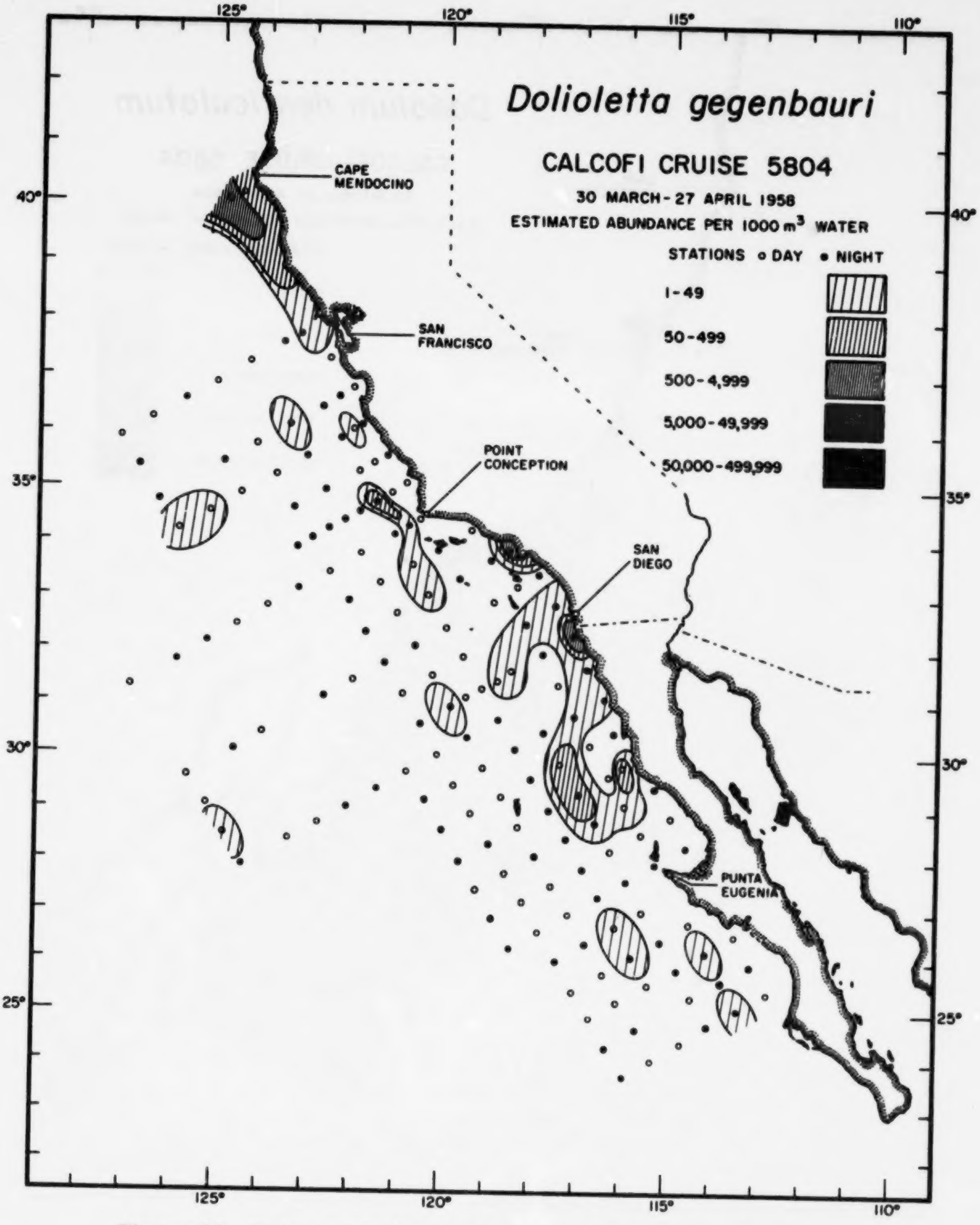

Dolioletta gegenbauri
CALCOFI CRUISE 5804
30 MARCH - 27 APRIL 1958
ESTIMATED ABUNDANCE PER 1000 m³ WATER
STATIONS ○ DAY ● NIGHT
1-49
50-499
500-4,999
5,000-49,999
50,000-499,999
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°

Figure 88. Estimated Abundance of Dolioletta gegenbauri (from Berner, 1967)

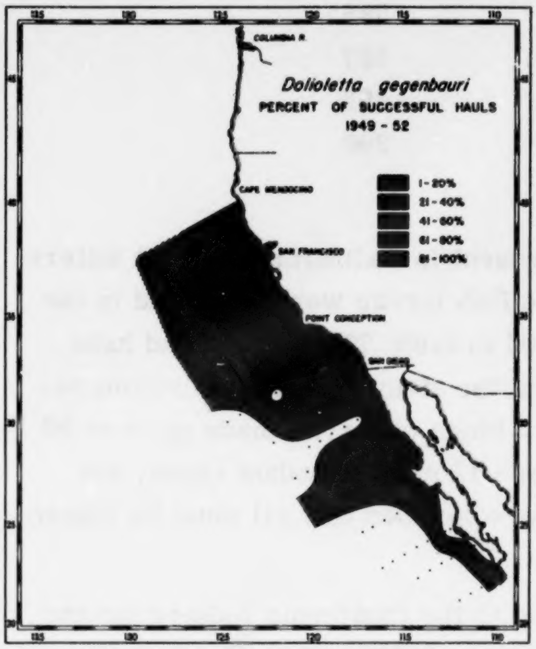

Dolioletta gegenbauri
PERCENT OF SUCCESSFUL HAULS
1949 - 52
1-20%
21-40%
41-60%
61-80%
81-100%
COLUMBIA R.
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
135
130
125
120
115
110

Figure 89. Percentage of Successful Hauls for Dolioletta gegenbauri during March, June, and September 1949-1952 (from Berner, 1960)

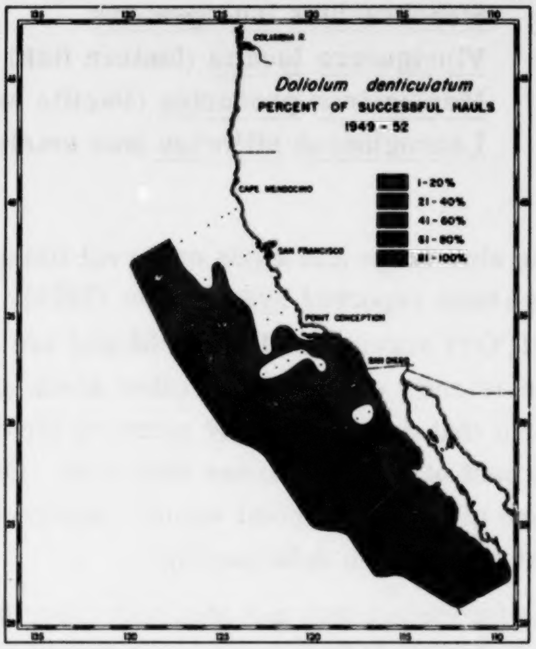

Doliolum denticulatum
PERCENT OF SUCCESSFUL HAULS
1949 - 52
1-20%
21-40%
41-60%
61-80%
81-100%
COLUMBIA R.
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
135
130
125
120
115
110

Figure 90. Percentage of Successful Hauls for Doliolum denticulatum during March, June, and September 1949-1952 (from Berner, 1960)

Commercial Fisheries

The abundant life in California waters, unlike off the East Coast, is not restricted primarily to the continental shelf but extends into the deep waters offshore. These plankton-rich waters support a variety of fish in relatively large numbers. A summary of the fishes collected in eight cruises (1961-1968) in the southern California region by Berry and Perkins (1966), included some 52,000 specimens, representing 189 species, belonging to 71 families and 16 orders. Most species collected belonged to the Orders Isospondyli (herring and anchovy), Iniomi (lizard fish, lantern fish), and Percomphi (sea bass, sun fish). The Order Isospondyli constituted 56 percent of all specimens, and the most abundant species was the northern anchovy (Engraulis mordax). The most abundant species collected in a single tow consisted of:

Engraulis mordax (northern anchovy)	9000 specimens
Lampanyctus mexicanus (lantern fish)	3000
Ceratoscopetus townsendi	944

Stenobrachius leucopsaurus	735
Vinciguerra lucetia (lantern fish)	537
Merluccinus productus (Pacific hake)	495
Leuroglossus stilbrius (sea smelt)	396

The abundance and kinds of larval fishes present in California Current waters have been reported by Ahlstrom (1965). The fish larvae were collected in the CalCOFI surveys of 1955-1958 and are listed in table 77. Anchovy and hake consistently outranked all other kinds during the study period. Ahlstrom reports that during the four years of study, 12 kinds of larvae made up over 90 percent of the fish larvae observed. Of these 12 most abundant types, six were of no commercial value. However, he concluded that all must be important in food web relationships.

The important fish and shellfish contributing to the California fishery for the period 1955-1966 are given in table 78 (Ahlstrom, 1968). Tuna, anchovy, mackerel, squid, rockfish, and crabs were the large contributors in the 1966 catch. The total catch exhibits a declining trend, due largely to the smaller catches of albacore, Pacific mackerel, sardines, and oysters during the time periods indicated. However, increased landings were noted in the bonito, anchovy, and crab fisheries. The 15 important California fisheries, based on the 1967 landings reported by the California Department of Fish Game, are given in table 79 (Heimann and Frey, 1968). The important California fisheries, based on value and landings as taken from the Fisheries Statistics of U.S. 1967 (Lyles, 1969), are given in table 80. The lists are comparable, with tuna, salmon, and crab fisheries appearing as the most valuable; and anchovy, mackerel, and squid ranking high in terms of volume of fish caught. Table 81 contains the ten important fisheries of the southern California region -- Santa Barbara, San Pedro, and San Diego -- Lyles (1969). This region is a large contributor to the California fisheries; eight of the important species are landed primarily in this region. The landings reported for the southern region (Santa Barbara, San Pedro, and San Diego) are approximately four times that reported for the northern region (Monterey to the Oregon border). The fish landings for the San Pedro region (Point Dume to San Onofre) represent about 60 percent of the landings for the entire California region (Lyles, 1969). Descriptions of some of the commercially important fisheries are presented in tables 82 through 86.

Table 77. Relative Abundance of Fish Larvae in California Current Region Based on Yearly Summaries of Larvae Obtained in Plankton Collection from CalCOFI Survey Cruises 1955-1958 (from Ahlstrom, 1965)

	1955			1956			1957			1958		
	Number Taken	Percentage of Total	Rank*	Number Taken	Percentage of Total	Rank*	Number Taken	Percentage of Total	Rank*	Number Taken	Percentage of Total	Rank*
Engraulis mordax (anchovy)	140,183	39.03	1	134,931	33.05	1	146,631	29.70	1	205,457	45.21	1
Merluccius productus (fluke)	60,090	16.73	2	94,277	23.10	2	78,283	15.86	2	58,368	12.84	2
Sebastodes spp. (rockfish)	29,344	8.17	3	29,144	7.14	3	36,473	7.39	4	23,931	5.27	4
Citharichthys spp. (sanddab)	20,411	5.68	4	23,635	5.79	4	15,813	3.20	9	6,655	1.46	11
Leuroglossus stilbius (sea smelt)	15,111	4.21	5	18,620	4.56	5	29,506	5.98	5	4,859	1.07	12
Sardinops caerulea (sardine)	14,121	3.93	6	15,523	3.80	6	9,833	1.99	11	11,423	2.51	7
Trachurus symmetricus (mackerel)	13,246	3.69	7	8,027	1.97	10	20,006	4.05	6	6,409	1.41	10
Lampanyctus mexicanus (lantern fish)	13,165	3.67	8	10,802	2.65	8	16,207	3.28	8	16,514	3.63	5
Vinciguerria lucetia (lantern fish)	12,654	3.52	9	9,832	2.41	9	55,114	11.17	3	55,756	12.27	3
Lampanyctus leucopsarus (lantern fish)	7,454	2.08	10	15,125	3.71	7	16,808	3.40	7	11,892	2.62	6
Diogenichthys laternatus (lantern fish)	4,771	1.33	11	3,158	0.77	13	11,603	2.35	10	7,061	1.55	8
Bathylagus wesethi (deep sea smelt)	3,245	0.90	12	2,146	0.52	17	6,347	1.29	12	7,021	1.54	9
Lampanyctus ritteri (lantern fish)	1,988	0.55	13	1,924	0.47	18	2,789	0.56	14	3,091	0.68	13
Pneumatophorus diego (mackerel)	1,950	0.54	14	1,520	0.37	20	1,865	0.38	18	1,273	0.28	20
Electrona spp.	1,823	0.51	15	1,852	0.45	19	1,415	0.29	22	1,775	0.39	15
Bathylagus ochotensis	1,301	0.36	18	2,231	0.55	15	1,078	0.22	25	1,550	0.34	16
Melamphaes spp.	775	0.22	25	1,051	0.26	24	1,328	0.27	24	1,255	0.28	21
Cyclothone spp.	1,532	0.43	16	814	0.20		2,880	0.58	13	2,795	0.62	14
Tarletonbeania crenularis	999	0.28	21	3,352	0.82	12	1,570	0.32	21	526	0.12	
Argentina sialis	832	0.23	24	1,288	0.32	22	1,400	0.28	23	276	0.06	
Prionotus spp.				2,470	0.60	14	2,731	0.55	15	1,307	0.29	19
Synodus spp.	641	0.18		958	0.23	25	2,338	0.47	17	1,219	0.27	23
Pleuronichthys spp.	1,038	0.29	19	1,118	0.27	23	579	0.12		164	0.04	
Diaphus theta	1,022	0.28	20	3,562	0.87	11	713	0.14		588	0.13	
Cynoscion spp.	860	0.24	23	104	0.02		31	0.06		1,350	0.30	18
Symphurus atricauda	73	0.02		1,373	0.34	21	1,603	0.32	20	222	0.05	
Ceratoscopelus townsendi	446	0.12		222	0.05		2,598	0.53	16	1,409	0.31	17
Symbolophorus californiense	653	0.18		462	0.11		1,645	0.33	19	1,236	0.27	22
Icichthys lockingtoni	1,385	0.39	17	898	0.22		768	0.16		438	0.10	
Palometa simillima	933	0.26	22	611	0.15		797	0.16		114	0.02	
Tetragonurus spp.	490	0.14		2,154	0.53	16	708	0.14		60	0.01	
Stomias atriventer	411	0.11		81	0.02		271	0.05		1,188	0.26	24
Hygophum spp.	400	0.11		223	0.05		795	0.16		993	0.22	25
All others	5,808	1.62		14,652	3.60		21,023	4.26		16,280	3.58	
TOTAL	359,155	100.00		408,140	100.00		493,549	100.01		454,455	100.00	

*Rank includes first 25 only

Table 78. Average Yearly Landings of Fish and Shellfish by California Fishermen in 1955-60 and 1961-65, and Landings in 1966 (from Ahlstrom, 1968)

Fish and Shellfish	Average Yearly Catch 1955-60	Average Yearly Catch 1961-65	Catch in 1966
Tuna and tuna-like fishes:			
Albacore	35,124	36,075	18,189
Bluefin tuna	18,182	24,307	34,820
Skipjack	95,651	81,009	51,089
Yellowfin tuna	141,467	146,206	132,595
Bonito	2,031	4,584	19,148
Yellowtail	306	175	245
Pelagic wetfishes:			
Anchovy	24,261	5,151	62,280
Jack mackerel	58,458	87,877	40,976
Pacific herring	1,770	840	242
Pacific mackerel	42,821	33,362	4,515
Pacific sardine	90,952	16,145	878
Squid	12,321	13,254	19,026
Bottom fishes:			
Flatfish	19,050	20,417	22,145
Hake	1,017	91	69
Lingcod	1,377	1,067	798
Rockfish	15,574	9,984	10,058
Sablefish	2,232	2,154	3,216
Miscellaneous animal food	--	2,261	2,380
Other finfishes:			
Barracuda	947	506	319
White croaker	962	821	790
Salmon	6,712	8,478	9,445
White seabass	2,019	996	1,338
Shad	176	0	0
Shark and skate	903	882	796
Smelt and whitebait	702	597	684
Swordfish	379	203	469
Other	1,685	1,429	1,662
Crustaceans and molluscs:			
Crabs	16,698	4,938	12,674
Spiny lobster	575	489	487
Shrimp	1,817	1,687	1,228
Abalone	4,551	4,347	4,917
Clam (including mussel)	18	7	2
Octopus	14	30	18
Oyster	10,336	4,997	801
Total fish and shellfish	611,088	515,366	458,299

Table 79. Important California Fisheries, Based on Landings in 1967 (from Heimann and Frey, 1968)

	Rank by Weight Caught	Rank by Dollar Value
1.	Yellowfin tuna	Yellowfin tuna
2.	Skipjack tuna	Albacore tuna
3.	Albacore tuna	Skipjack tuna
4.	Anchovy	Salmon
5.	Jack mackerel	Market crab
6.	Pacific bonito	Bluefin tuna
7.	Squid	Jack mackerel
8.	Bluefin tuna	Pacific bonito
9.	Market crab	Abalone
10.	Rockfish	Anchovy
11.	Salmon	Rockfish
12.	Dover sole	English sole
13.	English sole	Dover sole
14.	Abalone	Squid
15.	Sable fish	Sable fish

Table 80. Important California Fisheries Ranked by Value, 1967 Landings (from Lyles, 1969)

		Value ($)	Weight (lb)	
1.	Tuna (albacore)	3,352,578	17,572,400	(5)*
2.	Salmon (chinook-king)	2,325,714	3,951,500	(10)
3.	Crab (dungeness)	2,032,967	11,716,600	(6)
4.	Salmon (silver coho)	1,619,478	3,450,200	
5.	Jack mackerel	1,447,132	38,193,900	(2)
6.	Abalone	859,824	884,500	
7.	Bonito	713,660	17,841,500	(4)
8.	Anchovies	701,365	69,609,400	(1)
9.	Rockfish	669,650	9,647,500	(7)
10.	Sole (English)	510,331	5,821,900	(8)
Others:				
	Squid	437,766	19,601,900	(3)
	Sole (dover)	466,234	7,215,000	(9)

*Numbers in parentheses indicate rank by weight of catch.

Table 81. Catch (1967) of the Ten Most Valuable California Fisheries in the Southern California Region--Santa Barbara, San Pedro and San Diego (from Lyles, 1969)

	Value ($)	Weight (lb)
Tuna, albacore	2,006,068	10,295,900
Tuna, yellowfin	19,404,938	141,490,500
Salmon (king)	36,826	67,600
Crab (dungeness)	2,240	5,600
Salmon (silver coho)	17,934	41,800
Jack mackerel	1,410,543	37,258,400
Abalone	855,422	879,700
Bonita	890,935	21,212,800
Anchovy	551,354	52,929,300
Rockfish	315,952	3,967,100
Sole (English)	28,439	379,000

Table 82. Details on the Anchovy Fishery

Northern anchovy *Engraulis mordax*

	Characteristics	Data Source*
Landings and economic importance	N. Cal. 16,800,000 lb ($166,709)	1
	S. Cal. 52,900,000 lb ($551,354)	1
	Total 69,700,000 lb ($718,063)	1
	canning industry	2
	bait industry	3
Geographical range	Pacific coast from British Columbia to to lower tip of Baja California -- major fishing area S. California from San Francisco to Magdalena Bay	3
Habitat preferences		
Water	coastal waters (20 mi)	2
Temperature	14.5-20.0 C	4
Food sources		
Adults	indiscriminate daytime filter feeders chiefly crustaceans (copepods)	4
Growth	short lived: 4 yr, rarely to 7 yr; 5.6 in. at 2 yr, 7.0 in. at 4 yr	4
Mobility-migration		
Horizontal	fish tagged at San Francisco → Monterey Bay, at Monterey Bay → S. California, at S. California → Monterey Bay	5
Behavioral characteristics		
Schooling	coastal pelagic schooling	
Temperature	10-25°C summer, 5-20°C winter	6
Salinity	>32.5, <34.5‰	6
Other	preyed upon by nearly all predators -- major item in food web	2
Spawning		
Area	within 60 mi of shore	
Time of Year	female spawns 2-3 times per year, 20-30,000 eggs	
Other	sexual maturity reached by end of first year	

*1. Lyles, 1969 2. Miller, 1956 3. CalCOFI, 1953
4. Baxter, 1967 5. Messermith et al, 1969 6. Reid, 1967

Table 83. Details on the Albacore Fishery

Albacore *Thunnus germo*

Characteristics		Data Source*
Landings and economic importance	N. Cal. 7,572,000 lb ($1,400,755) S. Cal. 10,285,900 lb ($2,006,068) Total 17,857,900 lb ($3,406,823)	1
Geographical range	Pacific coast from Alaska to Baja California -- richest grounds: Columbia River to central Baja California	2
Habitat preferences		
Water depth	160-325 ft (along 50-68°F isotherm)	2
Temperature	60-65°F (never below 53°F)	
Other	offshore deep waters -- temperature oriented	
Food sources		
Fry	pelagic surface organisms or diurnal migrants from depths	2
Adults	small fish, crabs	
Growth	rate: average 7 lb/yr; young 4 cm/month	2
Mobility-migration		
Horizontal	transpacific migration between American coast, Hawaiian Islands, and Japan (to important feeding grounds)	2
Behavioral characteristics		
Schooling	schools follow isotherms	2
Temperature	57°F isotherm	
Spawning		
Area	ripe fish only in Hawaiian waters	2
Time of year	January to June -- by 4 to 5 yr old females	

*1. Lyles, 1969
2. Clements, 1955

Table 84. Details on the Jack Mackerel Fishery

Jack mackerel Trachurus symmetricus

Characteristics				Data Source*
Landings and economic importance (1967)	N. Cal.	935,500 lb	($ 36,589)	1
	S. Cal.	37,258,400 lb	($1,410,543)	1
	Total	38,193,900 lb	($1,447,132)	1
Geographical range	Gulf of Alaska to Baja California			2
	max density Pt. Conception to central Baja California, 80-240 mi offshore			3
Habitat preferences				
Temperature	above 11°C			4
Food sources				
Adults	feed at any time of day: small crustaceans, copepods, euphausiids, and pteropods			5
Growth	rate: 2 yr 250 mm, 3 yr 350 mm; most fish taken under 6 yrs ~ 20-38 cm			3
Mobility-migration	not known			
Behavioral characteristics				
Schooling	tend to school by size			3
Spawning	52,600 eggs; fish mature at 2 yr			3

*1. Lyles, 1969
2. Blunt, 1969
3. MacGregor, 1966
4. Ahlstrom, 1968
5. CalCOFI, 1953

Table 85. Details on the Pacific Hake Fishery

Pacific hake Merluccinus productus

	Characteristics	Data Source*
Landings and economic importance (1967)	California 14,440 lb ($309)	1
	considered trash fish -- unused resource; interest increased due to world market for fish meal and FPC+	2
Geographical range	Gulf of Alaska to Gulf of California; major concentration between Vancouver Island and Baja California	2
Habitat preferences		
Water depth	50-500 m (over continental shelf), generally within 10 ft of bottom	2
Temperature	47.5-65.3 F	2
Other	semi-pelagic	
Food sources		
Juveniles	primarily euphausiids - 2 species exclusively: Euphausia pacifica, Thysanoessa spinifera	3
Adults	fish and pandelids, squid, nocturnal feeders	
Growth	males grow slower (usually smaller) than females; 4 yr 18 in. 1.5 lb, 7 yr 22 in. 2 lb.	4
Mobility-migration		
Vertical	diel vertical movement	2
Horizontal	winter: S. Cal., summer: Washinton and N. Cal.	
Behavioral characteristics		
Schooling	long, narrow band (180 m)	2
Spawning		
Area	southern part of range	2
Time of year	winter	2
Other	spawn once a year; produce up to 496,000 eggs	4

*1. Lyles, 1969 2. Alverson and Larkins, 1969 3. Alton and Nelson, 1970
4. Nelson and Larkins, 1970 +Fish Protein Concentrate

Table 86. Details on the Abalone Fishery

Red abalone *Haliotis rufescens*

Characteristics		Data Source*
Landings and economic importance	N. Cal. 4,800 lb ($ 4,402) S. Cal. 879,700 lb ($855,422) Total 884,500 lb ($859,824)	1
Geographical range	Alaska to Cape San Lucas, Baja California	2
Habitat preferences		
Water depth	coastal band including kelp beds normally in low water ~ 100 ft	2
Type of bottom	rocky near shore, and kelp beds	2
Food sources	larvae: pelagic, plankton feeders, young feed on benthic diatoms and corraline algae	2
	adults: selective plant feeders -- *Macrocystis*, *Nerocystis*, and other macro algal forms	2
Growth	reach 11-in. diameter; 3-4 in. 5 yr	2
Mobility-migration	limited crawling movement	2
Behavioral characteristics	tend to segregate in depth by species; chief predators: otter, eel, cabezon, crab, octopuses, and starfish	2
Spawning		
Time of year	Spring and summer, depending on temperature (20°C) mature when 4 in.	2

*1. Lyles, 1969
2. Cox, 1962

Sport Fisheries

Sport fishing is an activity of increasing effort and interest. Pinkas et al (1968) estimated private boat sport fishing for 1964 in southern California at 2.8 million man hours, about 440,000 man days and 142,000 boat days (total time a private boat is engaged in a fishery activity). This effort yielded a catch of almost one million fish, consisting mostly of bonito, halibut, white croaker, sand bass, and kelp bass. As shown in table 87, the Pacific bonito, kelp bass, and sand bass are the most popular sport fish of this region (Pinkas et al, 1968). The average annual catch of sport fish for the years 1963-1966 in southern California was over seven million fish. For comparison, the total catch of sport fish for the northern California region (Oregon to Point Arguello) was estimated at about 800,000 specimens, roughly equivalent to 1.8 million pounds (Miller and Gotshall, 1965). The species composition of the northern California sport fishery is given in figure 91. The rockfish and salmon are the important sport fish of this area making up more than 75 percent of the total catch. The habitat and depth characteristics of the sport fish found in the northern California region, applicable in many instances to the situation in southern California, are shown by figures 92 and 93. The data illustrate that species vary with water depth and type of bottom.

Food Chains

The food chains or food webs associated with the marine environment are far more complex than those associated with the land environment. The latter generally contain a few trophic levels (producers, herbivores, carnivores) with primary production dependent almost entirely on spermatophytic plants. The ocean food webs are made up of six or more trophic levels and primary production is dependent almost entirely on the microscopic phytoplankton population, which is restricted to the relatively shallow depths of the euphotic zone.

A generalized production budget estimate in terms of organic matter for the marine environment of southern California is given by figure 94 (Emery, 1960). The figure shows that the efficiency of the conversion of solar energy into plant tissue is about 0.18, similar to that on good farm land. About 7.5 percent of the annual production of plants is converted to zooplankton tissue

Table 87. Fifteen Most Important Sport Fish in Southern California Marine Waters -- Representative Annual Catch, 1963-1966 (from Pinkas et al, 1968)

	Numbers
Pacific bonito	1,579,171
Kelp and sand bass	1,390,958
Rockfish species	661,220
California barracuda	565,166
White croaker	545,012
Queenfish	426,592
California halibut	280,369
Pacific halibut	231,708
Sculpin	220,129
Walleye surfperch	159,089
Shiner perch	133,386
Black perch	122,482
Barred surfperch	113,599
Albacore	109,650
Smelt, jack and top	96,809
	6,635,340
Other	690,663
Total	7,326,003

Private boat (1963-1966)	3,997,839
Piers and jetties (1963)	1,844,970
Private boats (1964)	981,460
Shoreline (1965-1966)	501,734
Total	7,326,003

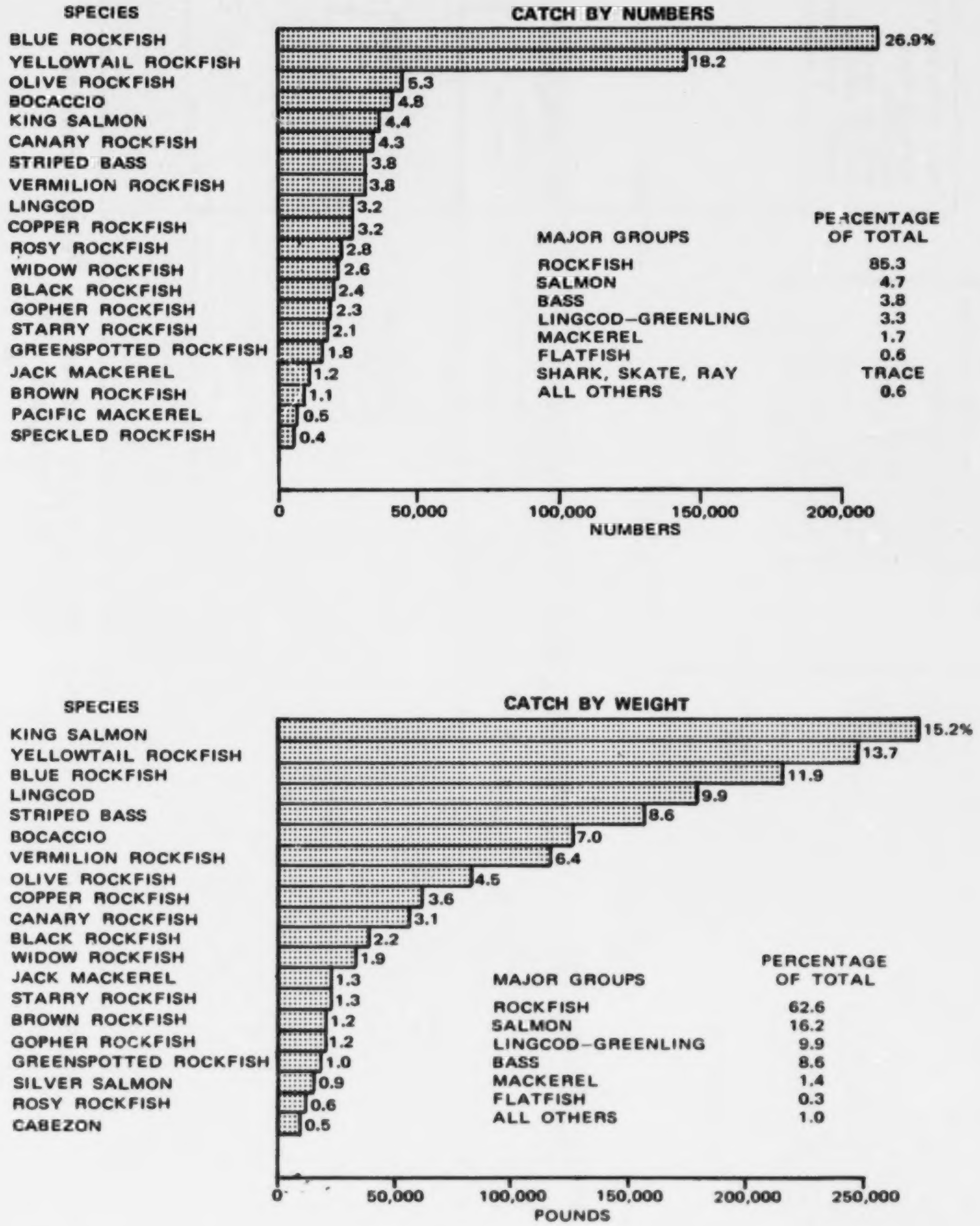


Figure 91. Total Catch and Composition Percentages of Twenty Most Frequently Recorded Fish Landed by Partyboats -- Crescent City to Avila, 1960 (from Miller and Gotshall, 1965)

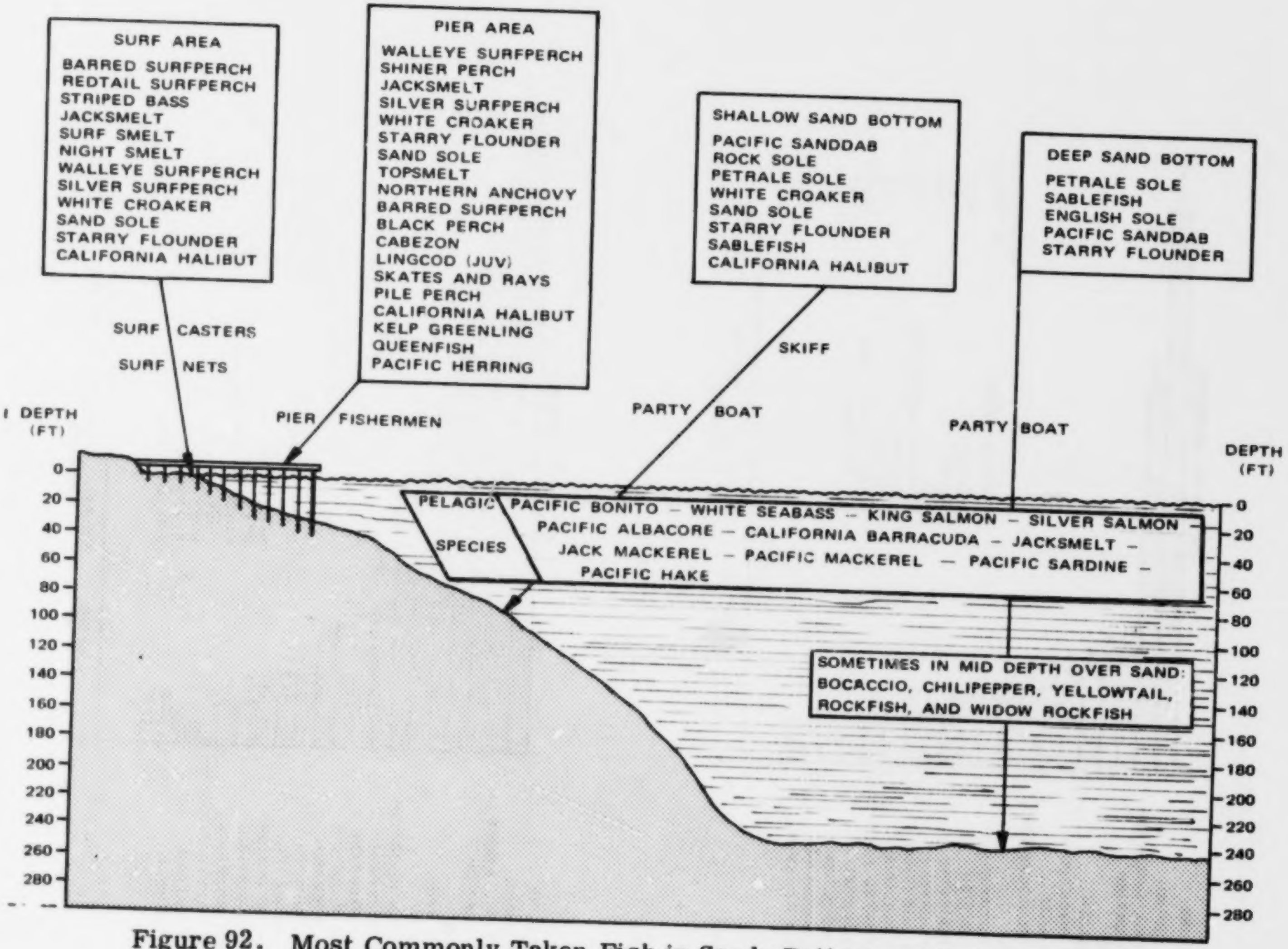

SURF AREA
BARRED SURFPERCH
REDTAIL SURFPERCH
STRIPED BASS
JACKSMELT
SURF SMELT
NIGHT SMELT
WALLEYE SURFPERCH
SILVER SURFPERCH
WHITE CROAKER
SAND SOLE
STARRY FLOUNDER
CALIFORNIA HALIBUT
PIER AREA
WALLEYE SURFPERCH
SHINER PERCH
JACKSMELT
SILVER SURFPERCH
WHITE CROAKER
STARRY FLOUNDER
SAND SOLE
TOPSMELT
NORTHERN ANCHOVY
BARRED SURFPERCH
BLACK PERCH
CABEZON
LINGCOD (JUV)
SKATES AND RAYS
PILE PERCH
CALIFORNIA HALIBUT
KELP GREENLING
QUEENFISH
PACIFIC HERRING
SHALLOW SAND BOTTOM
PACIFIC SANDDAB
ROCK SOLE
PETRALE SOLE
WHITE CROAKER
SAND SOLE
STARRY FLOUNDER
SABLEFISH
CALIFORNIA HALIBUT
DEEP SAND BOTTOM
PETRALE SOLE
SABLEFISH
ENGLISH SOLE
PACIFIC SANDDAB
STARRY FLOUNDER
SURF CASTERS
SURF NETS
PIER FISHERMEN
SKIFF
PARTY BOAT
PARTY BOAT
DEPTH (FT)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
PELAGIC SPECIES
PACIFIC BONITO – WHITE SEABASS – KING SALMON – SILVER SALMON –
PACIFIC ALBACORE – CALIFORNIA BARRACUDA – JACKSMELT –
JACK MACKEREL – PACIFIC MACKEREL – PACIFIC SARDINE –
PACIFIC HAKE
SOMETIMES IN MID DEPTH OVER SAND:
BOCACCIO, CHILIPEPPER, YELLOWTAIL,
ROCKFISH, AND WIDOW ROCKFISH
DEPTH (FT)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280

Figure 92. Most Commonly Taken Fish in Sandy Bottom and Pelagic Habitats -- Oregon to Point Arguello (from Miller and Gotshall, 1965)

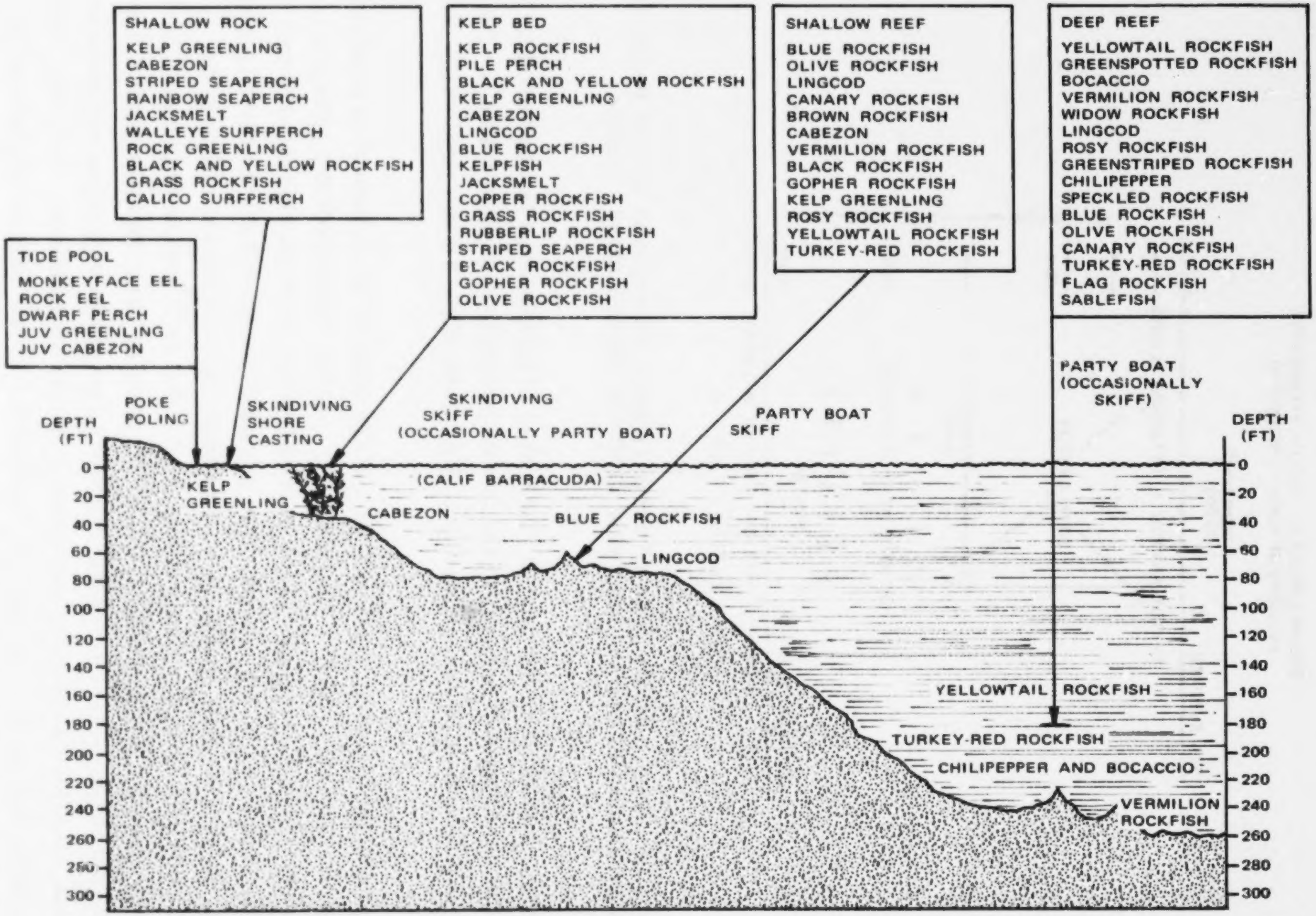

TIDE POOL
MONKEYFACE EEL
ROCK EEL
DWARF PERCH
JUV GREENLING
JUV CABEZON
SHALLOW ROCK
KELP GREENLING
CABEZON
STRIPED SEAPERCH
RAINBOW SEAPERCH
JACKSMELT
WALLEYE SURFPERCH
ROCK GREENLING
BLACK AND YELLOW ROCKFISH
GRASS ROCKFISH
CALICO SURFPERCH
KELP BED
KELP ROCKFISH
PILE PERCH
BLACK AND YELLOW ROCKFISH
KELP GREENLING
CABEZON
LINGCOD
BLUE ROCKFISH
KELPFISH
JACKSMELT
COPPER ROCKFISH
GRASS ROCKFISH
RUBBERLIP ROCKFISH
STRIPED SEAPERCH
BLACK ROCKFISH
GOPHER ROCKFISH
OLIVE ROCKFISH
SHALLOW REEF
BLUE ROCKFISH
OLIVE ROCKFISH
LINGCOD
CANARY ROCKFISH
BROWN ROCKFISH
CABEZON
VERMILION ROCKFISH
BLACK ROCKFISH
GOPHER ROCKFISH
KELP GREENLING
ROSY ROCKFISH
YELLOWTAIL ROCKFISH
TURKEY-RED ROCKFISH
DEEP REEF
YELLOWTAIL ROCKFISH
GREENSPOTTED ROCKFISH
BOCACCIO
VERMILION ROCKFISH
WIDOW ROCKFISH
LINGCOD
ROSY ROCKFISH
GREENSTRIPED ROCKFISH
CHILIPEPPER
SPECKLED ROCKFISH
BLUE ROCKFISH
OLIVE ROCKFISH
CANARY ROCKFISH
TURKEY-RED ROCKFISH
FLAG ROCKFISH
SABLEFISH
DEPTH (FT)
POKE POLING
SKINDIVING SHORE CASTING
SKINDIVING SKIFF (OCCASIONALLY PARTY BOAT)
PARTY BOAT SKIFF
PARTY BOAT (OCCASIONALLY SKIFF)
DEPTH (FT)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
KELP GREENLING
CABEZON
(CALIF BARRACUDA)
BLUE ROCKFISH
LINGCOD
YELLOWTAIL ROCKFISH
TURKEY-RED ROCKFISH
CHILIPEPPER AND BOCACCIO
VERMILION ROCKFISH

Figure 93. Most Commonly Taken Fish in Rocky Bottom Habitats -- Oregon to Point Arguello (from Miller and Gotshall, 1965)

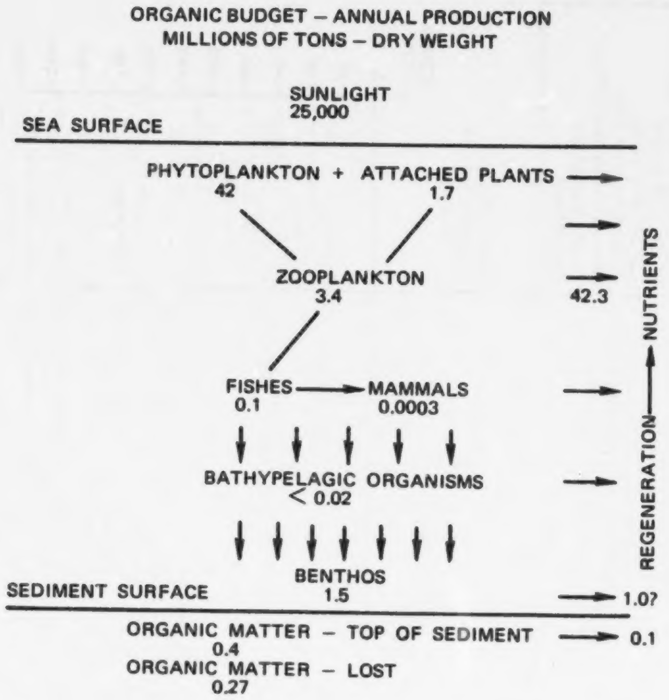
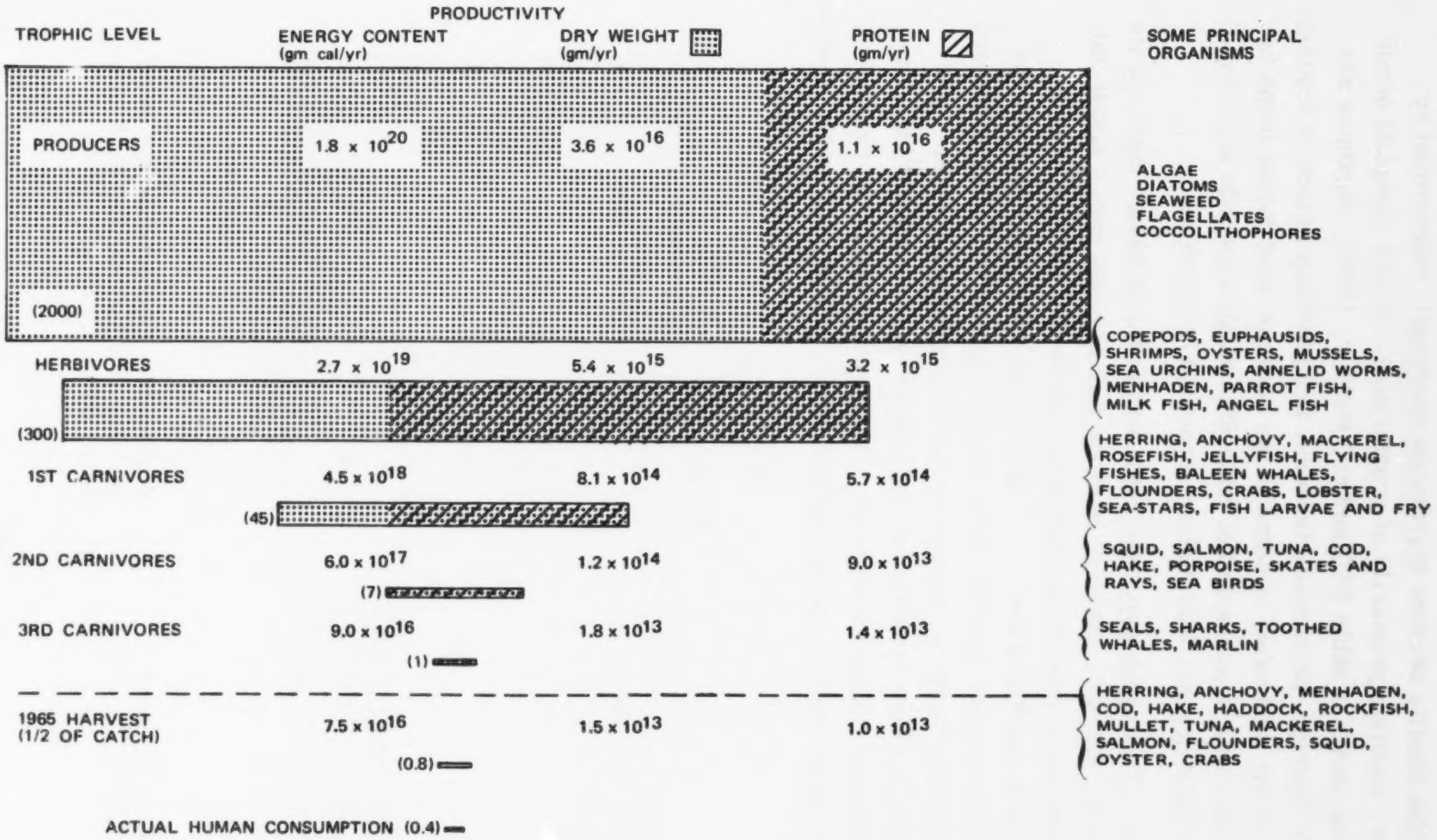

ORGANIC BUDGET – ANNUAL PRODUCTION
MILLIONS OF TONS – DRY WEIGHT
SUNLIGHT
25,000
SEA SURFACE
PHYTOPLANKTON + ATTACHED PLANTS
42
1.7
ZOOPLANKTON
3.4
42.3
FISHES
0.1
MAMMALS
0.0003
BATHYPELAGIC ORGANISMS
< 0.02
BENTHOS
1.5
SEDIMENT SURFACE
1.0?
ORGANIC MATTER – TOP OF SEDIMENT
0.4
0.1
ORGANIC MATTER – LOST
0.27
REGENERATION
NUTRIENTS

Figure 94. Approximate Flow Chart of Organic Matter and Annual Production of the Various Biozones of Southern Californa (from Emery, 1960)

and about 3 percent of the annual production of zooplankton is converted to fish tissue (about 0.2 percent of the annual production of plant tissue). The benthic production is approximately 3.4 percent of the annual production of plants.

The productivity and general food web of the marine environment is given by figure 95 (CalCOFI, 1967). Zooplankton, bottom filter feeders, grazers, and some small fish comprise the second trophic level (herbivores); small plankton feeding fish and carnivorous crustaceans constitute the third trophic level; the larger carnivorous fish, molluscs, and mammals make up the fourth and fifth levels. The production of 3.6×10^{16} grams of primary food ultimately could produce only 1.8×10^{13} grams of carnivores through a five-level food chain. The food chain of some large plankton feeding vertebrates (whales, sharks) is considerably shorter and more efficient. However, these food chains are highly specialized, involving a small number of species in the system (e.g., krill-whale food chain).



NOTES:
1. ASSUMED ECOLOGICAL EFFICIENCY IS 15 PERCENT.
2. MOST ORGANISMS FEED ON MORE THAN ONE TROPHIC LEVEL, CHANGING DIET WITH AGE (ESPECIALLY WHEN YOUNG) AND AVAILABILITY OF FOOD.
3. FIGURES IN PARENTHESES REPRESENT AREAL INDEX.

Figure 95. Diagram Showing Total Marine Food Web -- Dotted and Hatched Areas Indicate Relative Total Productivities at Each Step (from CalCOFI, 1967)

Food utilized by the Pacific sardine (Sardinops caerulea), determined by stomach analyses, consists primarily of crustaceans. Small copepods occur most frequently as shown in table 88 (Hand and Berner, 1959). Sardines are omnivorous filter feeders, particulate feeders, and partially selective feeders. A determination of the food value of some of the common food forms found in the stomachs of sardines is presented in table 89; small copepods contribute 74 percent of the total organic food matter consumed by sardines.

The jack mackerel (Trachurus symmetricus), unlike the sardine, captures its food. Consequently, stomach analyses of these fish indicate only a small list of the possible planktonic food forms available (figure 96, CalCOFI, 1953). The sardine and jack mackerel are often found in the same schools; yet, the competition for food between them is insignificant (figure 97). Jack mackerel are primarily selective feeders, eating the larger planktonic forms. Over 90 percent of the food items consisted of only three types: euphausiids, large copepods, and pteropods (small molluscs). On the other hand, the sardine's food consisted of many types including particulates, diatoms, and small copepods.

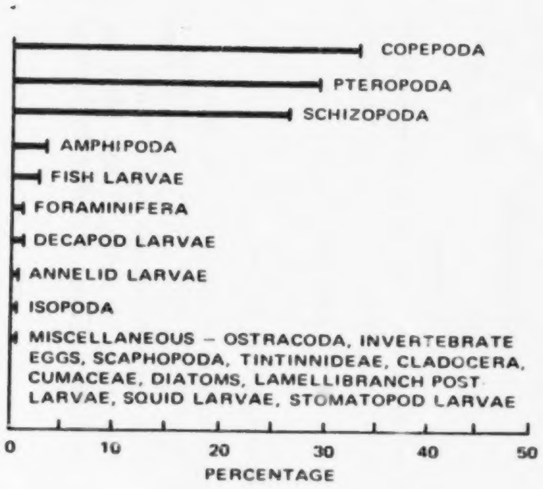


Figure 96. Food of the Jack Mackerel (from CalCOFI, 1953)

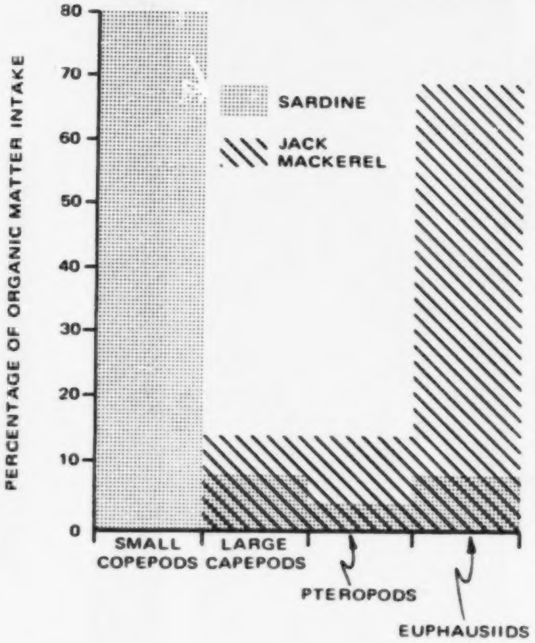


Figure 97. Competition for Food between the Sardine and Jack Mackerel (from CalCOFI, 1953)

Table 88. Frequency of Occurrence of the Organisms Found in the Stomachs of 273 Sardines (from Hand and Berner, 1959)

Organism	Percentage of Occurrence
Small copepods	100
Larvaceans	93
Fish eggs	79
Diatoms	75
Chaetognaths	73
Dinoflagellates	71
Large copepods	70
Cladocerans	65
Cyphonautes larvae	64
Euphausiid furcilia and calyptopsis larvae	50
Gastropods (adult and larvae)	49
Lamellibranch larvae	48
Copepod nauplii	47
Radiolarians and silicoflagellates	46
Euphasiid nauplii	40
Annelid larvae	36
Euphasiid eggs	32
Zoea larvae	29
Euphasiid adults	24
Amphipods	19
Barnacle nauplii	18
Fish larvae	17
Barnacle cyprids	16
Siphonophores	15
Salps	15
Mysids	13
Copepod eggs	10
Shrimp larvae	8
Brachiopod larvae	4
Ostracod	4
Foraminiferans	3
Doliolids	2
Cumaceans	1
Isopods	1

Table 89. Organic Matter -- Food Value of Common Items Found in Sardine Stomach (from Hand and Berner, 1959)

Organism	Size (mm)	Average Organic Matter per Specimen (mg)	Number of Specimens Ashed
Small copepods	0.9	0.04	100
Large copepods	1.8	0.07	100
Euphausiids	10.0	0.90	10
Anchovy eggs	0.9	0.10	100
Chaetognaths	13.0	0.10	10

Organism	Average Number in 571 Stomachs (Sardine)	Total Organic Matter (mg)	Percentage of Total
Diatoms	1.14×10^6	1.77	4.9
Dinoflagellates	33,000	0.70	1.9
Small copepods	666	26.64	74.2
Large copepods	20	3.40	9.5
Euphausiids	2	1.80	5.0
Chaetognaths	9	0.90	2.5
Fish eggs	7	0.70	1.9

Food of the Pacific hake (Merluccius productus) consists primarily of euphausiids,shrimp, and small fish (table 90, Alton and Nelson, 1970). The contribution of various food types to the total food intake of hake is presented in figure 98, Best (1963) has indicated that juvenile hake prefer pelagic red crab (Pleuroncodes planipes), euphausiids, and squid; adults prefer anchovy and other small fish, euphausiids, and the small clam (Solemya). Young hake are preyed upon by rockfish, albacore, larger hake, flounder, and sole while large hake are preyed upon by lancet fish, bluefin tuna, lingcod, rays, sharks, and sea mammals (seals, porpoises). The pacific hake are relatively abundant along the Pacific coast, estimated at about 200 million pounds (Lyles,

Table 90. Occurrence of Various Foods in Stomachs of Pacific Hake from Coastal Waters of Washington and Northern Oregon (from Alton and Nelson, 1970)

Types of Food	Stomachs Examined in Detail		Stomachs Examined Cursorily	
	Number	%	Number	%
Crustaceans	137	97.9	274	94.8
Euphausiids	126	90.0	268	92.7
Thysanoessa spinifera	98	70.0	--	
Euphausia pacifica	58	41.4	--	
Pandalids	12	8.6	6	2.1
Pandalus jordani	8	5.7	1	0.3
Sergestes similis	7	5.0	--	
Cragonids	3	2.1	--	
Crab larvae	5	3.6	--	
Mysids	1	0.7	--	
Crustacean remains	12	8.6	--	
Fish	35	25.0	7	2.4
Smelt	6	4.3		
Thaleichthys pacificus	7	5.0		
Engraulis mordax	5	3.6		
Ammodytes hexapterus	2	1.4		
Anoplopoma fimbria	1	0.7		
Clupea harengus pallasi	--		1	0.3
Fish remains	14	10.0		
Squid	1	0.7	--	
Stomachs containing food	140		289	

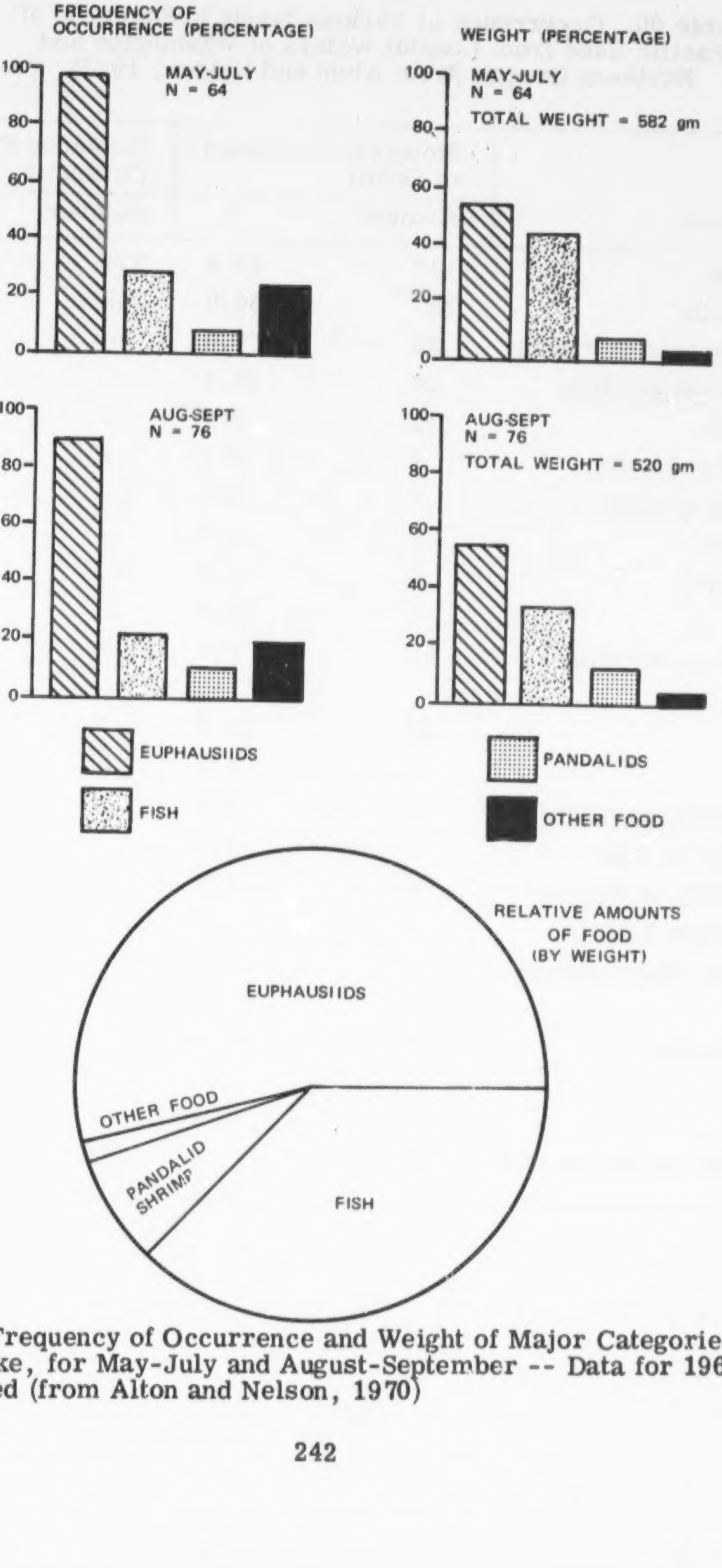


Figure 98. Frequency of Occurrence and Weight of Major Categories of Food of Pacific Hake, for May-July and August-September -- Data for 1965 and 1966 Combined (from Alton and Nelson, 1970)

1969). However, little use is made of this fishery except for animal food (Best, 1963). The food of the yellowtail, a popular sport fish, is shown in figure 99 (Baxter et al, 1960), the red crab, sardine, and anchovy occurring most frequently in stomach analyses.

From this brief examination, it appears that copepods, euphausiids, pteropods, red crabs, and forage fish (sardine, herring, anchovy) are important items in the food web of the California fishery.

Benthic Organisms

The type of substrate found in any locale influences the benthic population and the community structure of the area. Muds, silts, sands, and rocky, gravel, shell bottoms characteristically describe the bottom substrates found on the southern California shelf. The soft muds and silts predominate in off-shelf deep waters; sands dominate the inshore bottom; and rocky shell material characteristically appears near shore and follows the coastline contours. Silt bottoms rich in organic material are generally the more productive areas. In a study of the inshore bottom environment near San Elijo Lagoon, of some 200 or more plant and animal types identified only 16 were observed in sand bottom areas (Turner et al, 1965). In the survey of the southern California shelf, the Allan Hancock Foundation (1965) estimates the population of benthic organisms in or on fine silts and coarse sands to be on the order to $5000/m^2$ and $2500/m^2$, respectively.

A comprehensive study of the benthic forms of the southern California shelf has been reported by Jones (1969). This study reports observations of 1,473 different animal types of which 523 (35%) were polychaetes, 419 (28%) were crustaceans, 408 (28%) were molluscs, and 64 (4%) were echinoderms. Jones was able to identify only 60 percent of the organisms to the species level, indicating that identification of many of the benthic forms is still difficult or impossible. In addition to these forms, echiuroids and brachipods are sometime included in lists describing the dominant groups of organisms occupying the shelf area (the Allan Hancock Foundation, 1965).

Echiuroids are annelid worms showing a lack of segmentation and reduced pairs of setae. Listriolobus pelodes, the tongue worm, is the common species of the area. Brachipods are marine sessile forms which resemble molluscs, live in burrows, and frequently dominate bottom samples. The typical species

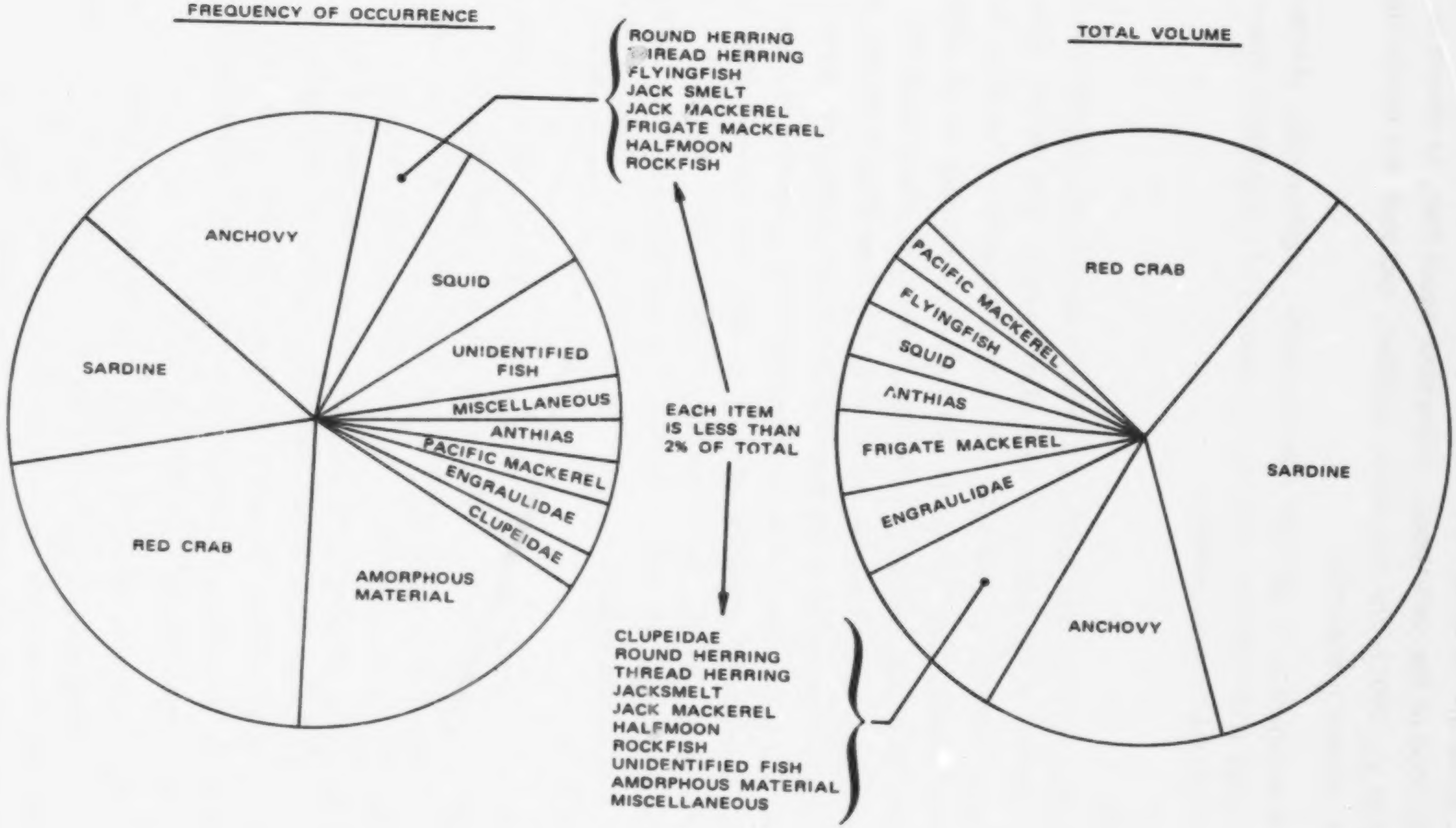


Figure 99. Frequency of Occurrence and Volume of Food Organisms Found in Yellowtail Stomachs (from Baxter et al, 1960)

of the area is Glottidea albida. The 50 top-ranked species observed in the study area are ranked according to frequency of occurrence (table 91), by population density (specimen/m^2, table 92), and an index of affinities (joint occurrences with other species in table 93, Jones (1969). Prionospio pinnata (a polychaete) was ranked first by frequency of occurrences, while Amphiodia urtica (a small red brittle star) was ranked first by density and affinity index. A list of the 28 prevalent species common to all three lists is presented in table 94. Amphiodia urtica obviously is the dominant species of the mainland shelf. However, the polychaetes comprise the most important single group, occurring at all depths, and in all kinds of sediments.

At least 10 bottom biological communities have been described (the Allan Hancock Foundation, 1965). Some of these associations are described here:

1. Listriolobus. Found off the Santa Barbara shelf. A biomass of some 100,000 tons is estimated for this community.
2. Amphiodia. Dominates soft bottoms and found generally at depths between 120 and 300 ft.
3. Amphiodia - Cardita. Also found off the Santa Barbara shelf but at depths below the Listriolobus community (180-300 ft).
4. Chaetopterus. A community found near shore in black muds at depths of 36-120 ft.
5. Pista-Nothria. Occurs at moderate depths and especially in the submarine canyons.

Amphiodia communities by far dominate the benthic communities of the shelf, occupying about 23 percent of the total shelf area (table 95). Jones (1969) considers three communities of major importance:

1. the Nothria-Tellina assemblage, which is restricted to the shallow portion of the shelf (10-35m);
2. the Listriolobus association, which is found in the intermediate depths of the shelf (25-70 m); and
3. the Amphiodia-Cardita community, which is confined to the outer portion of the shelf (50-105 m).

Table 91. The 50 Top-Ranked Species in the 176-Sample Set, Ranked by Frequency of Occurrence (from Jones, 1969)

Species	Rank	Frequency	Percent
nemerteans unknown (O)	1	176	100.0
Prionospio pinnata (P)	2	159	90.4
Amphiodia urtica (E)	3	153	87.0
Prionospio malmgreni (P)	4	149	84.5
Amphipholis squamata (E)	5	136	77.3
Pectinaria californiensis (P)	6	131	74.5
Pholoe glabra (P)	7	124	71.1
Goniada brunnea (P)	8	114	64.8
ostracods unknown (C)	9	109	61.9
Paraonis gracilis (P)	10	108	61.3
Spiophanes missionensis (P)	11	107	60.8
Tharyx tesselata (P)	13	105	59.7
Haploscoloplos elongatus (P)	13	105	59.7
tanaids unknown (O)	13	105	59.7
Terebellides stroemi (P)	15	103	58.5
Ampelisca brevisimulata (C)	16	101	57.4
Heterophoxus oculatus (C)	17	97	55.0
Laonice cirrata (P)	18	96	54.6
Sternaspis fossor (P)	19	95	54.0
Glycera capitata (P)	20	94	53.3
Haliophasma geminata (C)	21	93	52.8
Lumbrineris cruzenis (P)	23	92	52.3
Axinopsida serricata (M)	23	92	52.3
Gnathia crenulatifrons (C)	23	92	52.3
Cossura candida (P)	26	91	51.7
nematode unknown (O)	26	91	51.7
Glottidia albida (O)	26	91	51.7
Nepthys sp. (P)	28	90	51.2

C = crustaceans, E = echinoderm, M = mollusc, O = other taxa
P = polychaete

Table 91 (Cont'd)

Species	Rank	Frequency	Percent
Ampelisca cristata (C)	29	89	50.5
Telepsavus costarum (P)	30.5	87	49.4
Axiothella rubrocincta (P)	30.5	87	49.4
Sthenelanella uniformis (P)	32.5	84	47.7
Aricidea suecica (P)	32.5	84	47.7
Nereis procera (P)	34	83	47.2
Aricidea lopezi (P)	35	80	45.5
Nephtys ferruginea (P)	37	77	43.8
pelecypods unknown (M)	37	77	43.8
Paraphoxus bicuspidatus (C)	37	77	43.8
Cadulus sp. (M)	40	76	43.2
Paraphoxus similus (C)	40	76	43.2
Ampelisca pacifica (C)	40	76	43.2
Westwoodilla caecula (P)	42	74	42.0
Metaphoxus frequens (C)	43	73	41.5
Oxydromus arenicolus (P)	44	72	40.8
Nuculana taphria (M)	45.5	71	40.3
Pinnixa sp. (C)	45.5	71	40.3
Diastylidae unknown (C)	47	70	39.8
Chaetodermatina unknown (M)	49	69	39.2
Ampelisca pugetica (P)	49	69	39.2
Leptosynapta albicans (E)	49	69	39.2

Table 92. The 50 Top-Ranked Species in the 176-Sample Set, Ranked by Population Density -- Specimens/ Square Meter (from Jones, 1969)

Species	Rank	Density
Amphiodia urtica (E)	1	359.1
ostracods unknown (C)	2	272.9
Amphicteis scaphobranchiata (P)	3	93.8
Prionospio malmgreni (P)	4	92.8
brown ostracod (C)	5	61.7
Tharyx multifilis (P)	6	61.6
Axinopsida serricata (M)	7	54.7
Tharyx tesselata (P)	8	53.6
Paraphoxus bicuspidatus (C)	9	47.6
Pectinaria californiensis (P)	10	45.3
Prionospio pinnata (P)	11	44.5
Amphipholis squamata (E)	12	39.5
Pholoe glabra (P)	13	36.1
Lumbrineris cruzensis (P)	14	35.9
Ampelisca brevisimulata (C)	15	35.7
Haploscoloplos elongatus (P)	16	31.7
Tellina buttoni (M)	17	30.5
Aricidea lopezi (P)	18	28.7
Paraonis gracilis (P)	19	28.6
nemerteans unknown (O)	20	28.0
Chloeia pinnata (P)	21	27.4
Paraphoxus abronius (C)	22	27.3
nematodes unknown (O)	23	27.2
tanaids unknown (C)	24	26.3
Dorvillea articulata (P)	25	25.7
Mediomastus californiensis (P)	26	25.1
Bittium subplanatum (M)	27	24.3
Glottidia albida (O)	28	24.2
Heterophoxus oculatus (C)	29	23.8

C = crustacean, E = echinoderm, M - mollusc, O - other taxa
P = polychaete

Table 92 (Cont'd)

Species	Rank	Density
Cossura candida (P)	30	23.7
Ampelisca cristata (C)	31	22.9
Spiophanes missionensis (P)	32	22.8
Nephtys sp. (P)	33	22.7
polychaete unknown (P)	34	22.5
Photis brevipes (C)	35	21.4
Rochefortia aleutica (C)	36	19.7
Magelona sacculata (P)	37	19.6
Chaetozone corona (P)	38	19.4
Cardita ventricosa (M)	39	18.8
Tharyx sp. (P)	40	18.5
Adontorhina cyclia (M)	41	18.3
Metaphoxus frequens (C)	42	18.0
calanoid copepod (C)	43	17.7
Glycera capitata (P)	44	17.6
Paraphoxus similis (C)	45	17.4
Paraphoxus epistomus (C)	46	16.6
Ampelisca macrocephala (C)	47	15.8
Sternaspis fossor (P)	48	15.7
Diastylopsis tenuis (C)	49	15.3
Psephidia lordi (M)	50	15.1

Table 93. The 50 Top-Ranked Species in the 176-Sample Set, Ranked by Number of Affinities with Other Species of the Sample Set (from Jones, 1969)

Species	Rank	Affinities
Amphiodia urtica (E)	1	88
Prionospio pinnata (P)	2	79
nemerteans unknown (O)	3	75
Prionospio malmgreni (P)	4	73
Pectinaria californiensis (P)	5	71
Amphipholis squamata (E)	6	69
Pholoe glabra (P)	7	65
tanaids unknown (C)	8	56
Ampelisca brevisimulata (C)	9	55
Terebellides stroemi (P)	10	51
Gnathia crenulatifrons (C)	11.5	50
Heterophoxus oculatus (C)	11.5	50
Goniada brunnea (P)	14.5	48
ostracods unknown (C)	14.5	48
Paraphoxus similis (C)	14.5	48
Axinopsida serricata (M)	14.5	48
Ampelisca pacifica (C)	17.5	47
Paraonis gracilis (P)	17.5	47
Spiophanes missionensis (P)	19.5	46
Paraphoxus bicuspidatus (C)	19.5	46
Haliophasma geminata (C)	21 5	45
Glycera capitata (P)	21.5	45
Metaphoxus frequens (C)	23	42
Sternaspis fossor (P)	24	41
Haploscoloplos elongatus (P)	25	40
Diastylidae unknown (C)	27	39
Cossura candida (P)	27	39
Tharyx tesselata (P)	27	39

C = crustacean, E = echinoderm, M = mollusc, O = other taxa, P = polychaete

Table 93 (Cont'd)

Species	Rank	Affinities
Lumbrineris cruzensis (P)	29	38
Ampelisca pugetica (C)	29	38
Sthenelanella uniformis (P)	31	37
Glottidia albida (O)	32	36
Westwoodilla caecula (C)	33	34
Nephtys ferruginea (P)	34	32
Ampelisca cristata (C)	37	29
Laonice cirrata (P)	37	29
Ampelisca macrocephala (C)	37	29
Eudorella A (C)	37	29
Nicippe tumida (C)	41	28
Leptosynapta albicans (E)	41	28
Chaetodermatina unknown (M)	41	28
Nemocardium centifilosum (M)	41	28
Adontorhina cyclia (M)	41	28
Chloeia pinnata (P)	44	26
Telepsavus costarum (P)	46	25
Nephtys sp. (P)	46	25
nematode unknown (O)	46	25
Aricidea lopezi (P)	48	23
Compsomyax subdiaphana (M)	49	21
Tellina buttoni (M)	50	20

Table 94. Prevalent Species Common to Listings in Tables 91, 92, and 93 -- Listed by Phyletic Categories and Ranked by Frequency of Occurrence (from Jones, 1969)

Species	Frequency	Affinities	Density
Polychaetes:			
Prionospio pinnata	90.4	79	28.0
Prionospio malmgreni	84.5	73	92.8
Pectinaria californiensis	74.5	71	45.3
Pholoe glabra	71.1	65	51.1
Paraonis gracilis	61.3	47	48.3
Spiophanes missionensis	60.8	46	22.8
Tharyx tesselata	59.7	39	53.6
Haploscoloplos elongatus	59.7	40	31.7
Sternaspis fossor	54.0	41	15.7
Glycera capitata	53.3	45	17.6
Lumbrineris cruzensis	52.3	38	35.9
Cossura candida	51.7	39	45.8
Nephtys sp.	51.2	25	24.2
Aricidea lopezi	45.5	23	28.7
Crustaceans:			
ostracods unknown	61.9	48	279.9
tanaids unknown	59.7	56	26.3
Ampelisca brevismulata	57.4	55	35.7
Heterophoxus oculatus	55.0	50	23.8
Ampelisca cristata	50.5	29	22.9
Paraphoxus bicuspidatus	43.8	46	47.6
Paraphoxus similis	43.2	48	17.4
Metaphoxus frequens	41.5	42	18.0
Echinoderms:			
Amphiodia urtica	87.0	88	359.1
Amphipholis squamata	77.3	69	39.5
Molluscs:			
Axinopsida serricata	52.3	48	54.7

Table 94 (Cont'd)

Species	Frequency	Affinities	Density
Other Taxa:			
nemerteans unknown	100.0	75	28.0
nematodes unknown	51.7	25	27.2
Glottidia albida	51.7	36	24.2

Table 95. Dominance of Benthic Communities on the Southern California Mainland Shelf, Spaced Statistically According to Area, Based on 150 Stations (from the Allan Hancock Foundation, 1965)

	Percentage of Total Shelf Area
Amphiodia	23
Listriolobus	7
Onuphis	6
Amphiodia/Pectinaria	5
Nothria sp.	5
Amphiodia/Cardita	4
Diopatra	4
Cardita	3
Astropecten	1
Chloeia	1
Chaetopterus/Lima	1
Sternaspis	1
Amphiodia/Onuphis	1
Lytechinus	1
Tharyx	1
	67
Diversified and unclassified	33
Total	100

Population densities of species making up these associations are plotted by depth and are shown by figures 100 through 103. The distribution of the major benthic communities of the southern California shelf from Point Conception to San Diego is shown by figures 104, 105, 106, and 107 (only the major, widely distributed, associates are mapped). The general distribution by depth of some important benthic groups is shown by figure 108.

Sponges, polychaetes, ophiuroids, crustaceans, and pelecypods are found at all depths from less than 10 meters to over 900 meters (Emery, 1960). The greatest biomass is found at about the 50-meter depth. The distribution of several representative species, with depth and sediment type, is shown by figures 109 and 110. Maximum populations of Amphiodia occur at depths of 200 ft and in silty, clay substrates. Cardita occurs at a similar depth, but in mud bottom. Listriolobus population peaks at about 120 ft and prefers bottoms of mud to silty clay. Maximum populations of Prionospia and Glottidia occur at depths less than 100 ft, and in silty to very fine sand bottoms.

The biomass of the benthic animals from the mainland shelf to the continental slope are compared in table 96 (Emery, 1960). Shelf areas are the most productive areas, while the basin and trough floors are the least productive. Although the benthos of the California coast appears to support a wide range of animals and plant forms, areas are known that are nearly devoid of life. The Santa Barbara, Santa Monica, and San Pedro Basins are impoverished areas containing only empty polychaete tubes or empty tests of forams and occasional shells of molluscs (Emery, 1960).

Large kelp beds can also be found in areas along the southern California coast (figure 111). The beds are restricted to depths of less than 100 ft and to areas of suitably rocky substrate (North and Schaeffer, 1964). In the past these beds encompassed a total area of 100 sq mi (260 km^2), but now the size of kelp beds is decreasing (North and Hubbs, 1968). Kelp beds are of interest because of the harvestable economic crop they represent and because of the animals that are associated with them (abalone, lobster, commercial and sport fish). Kelp yields several products of commercial value: animal and human food additives, fertilizers, and alginic acid. The annual harvest is over 100,000 wet tons, worth over a million dollars (North and Hubbs, 1968). The kelp bed habitat encourages and enhances the development of other animal

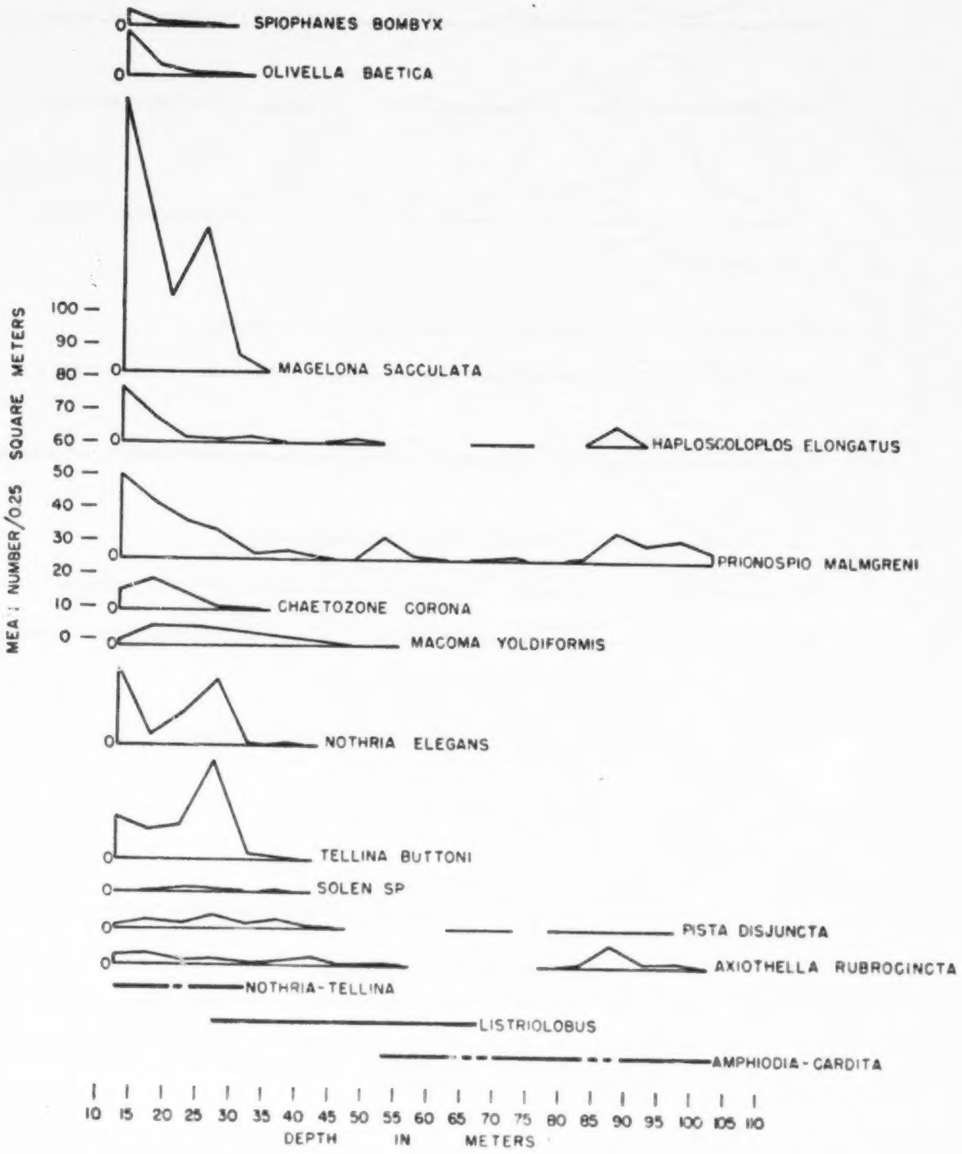


Figure 100. Mean Number of Benthic Organisms Sampled, by Depth (from Jones, 1969)

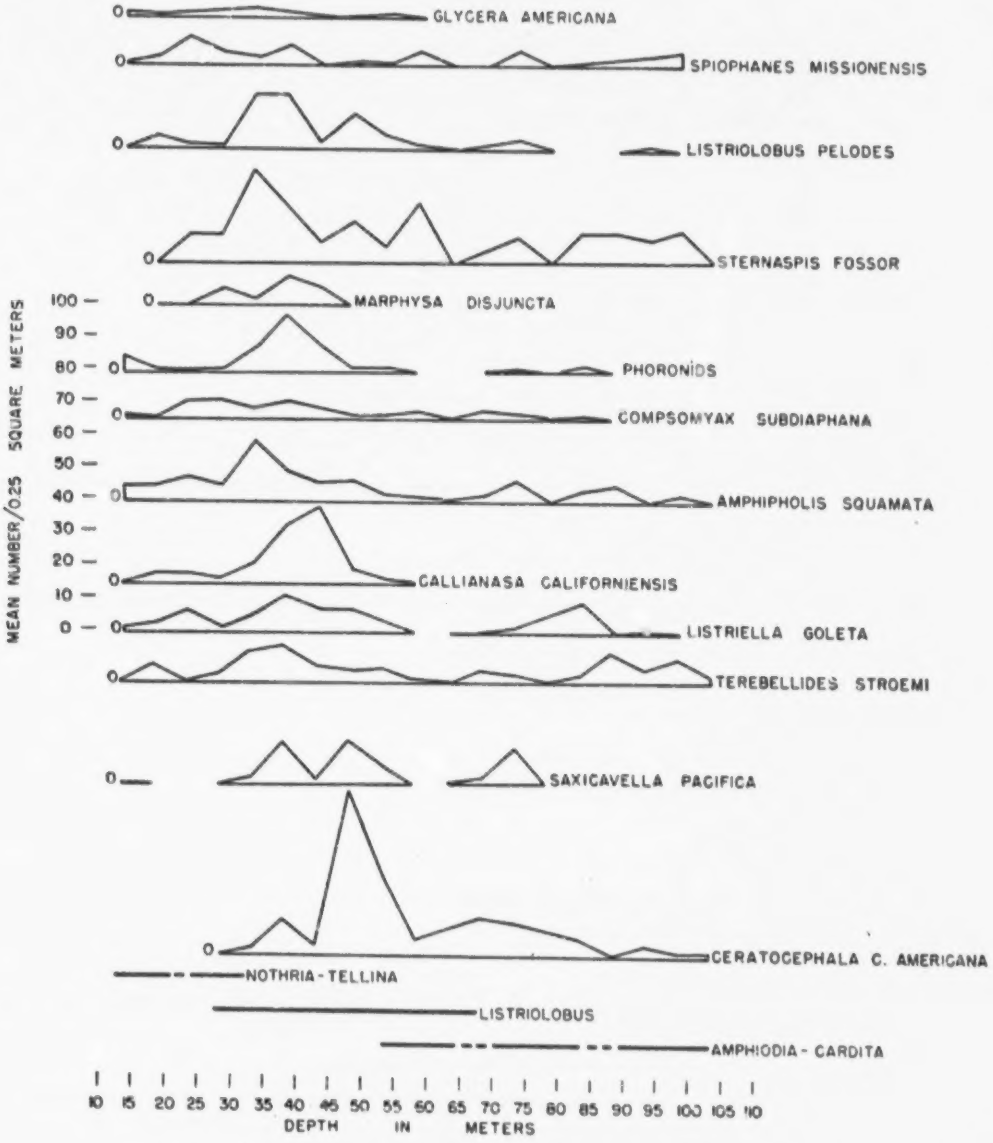


Figure 101. Mean Number of Benthic Organisms Sampled, by Depth (from Jones, 1969)

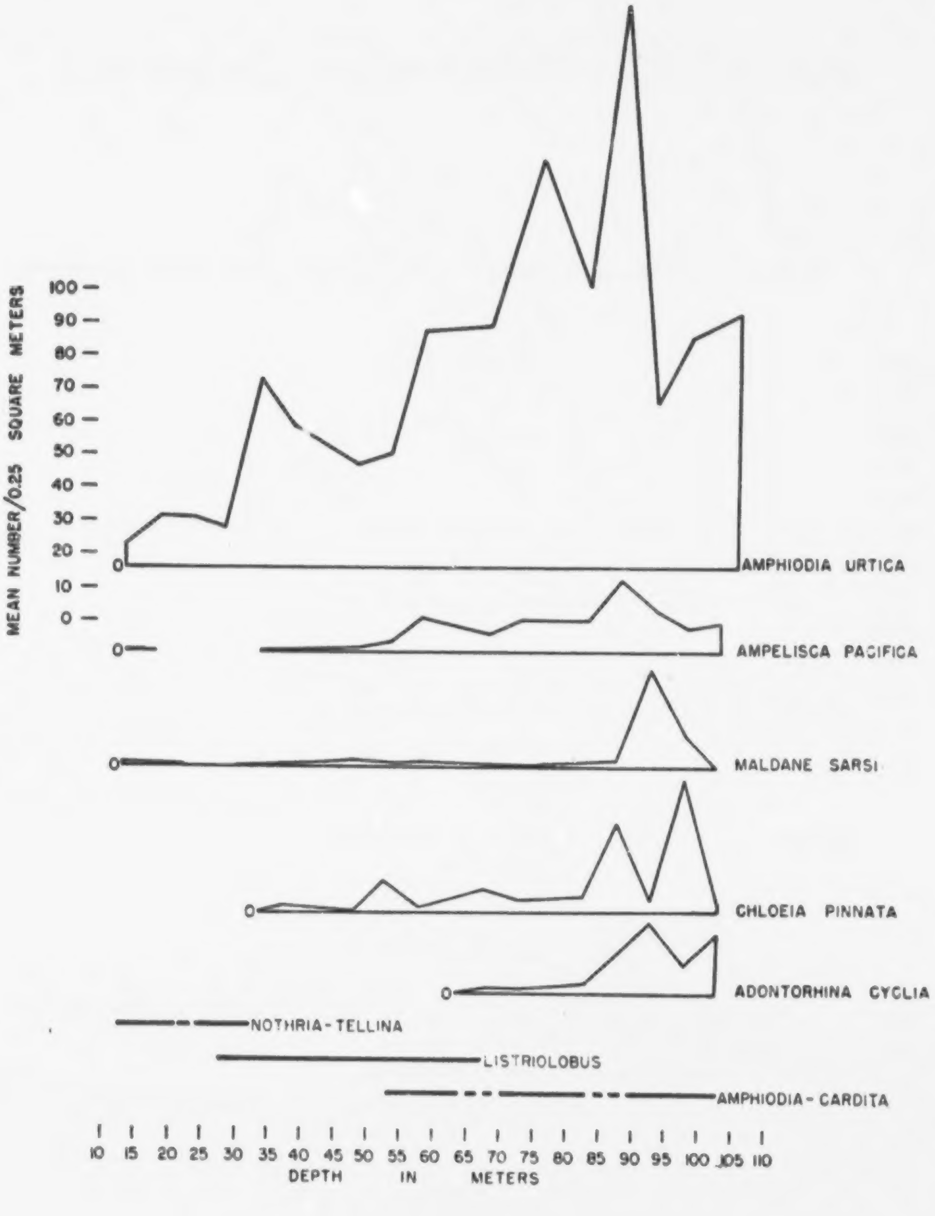


Figure 102. Mean Number of Benthic Organisms Sampled, by Depth (from Jones, 1969)

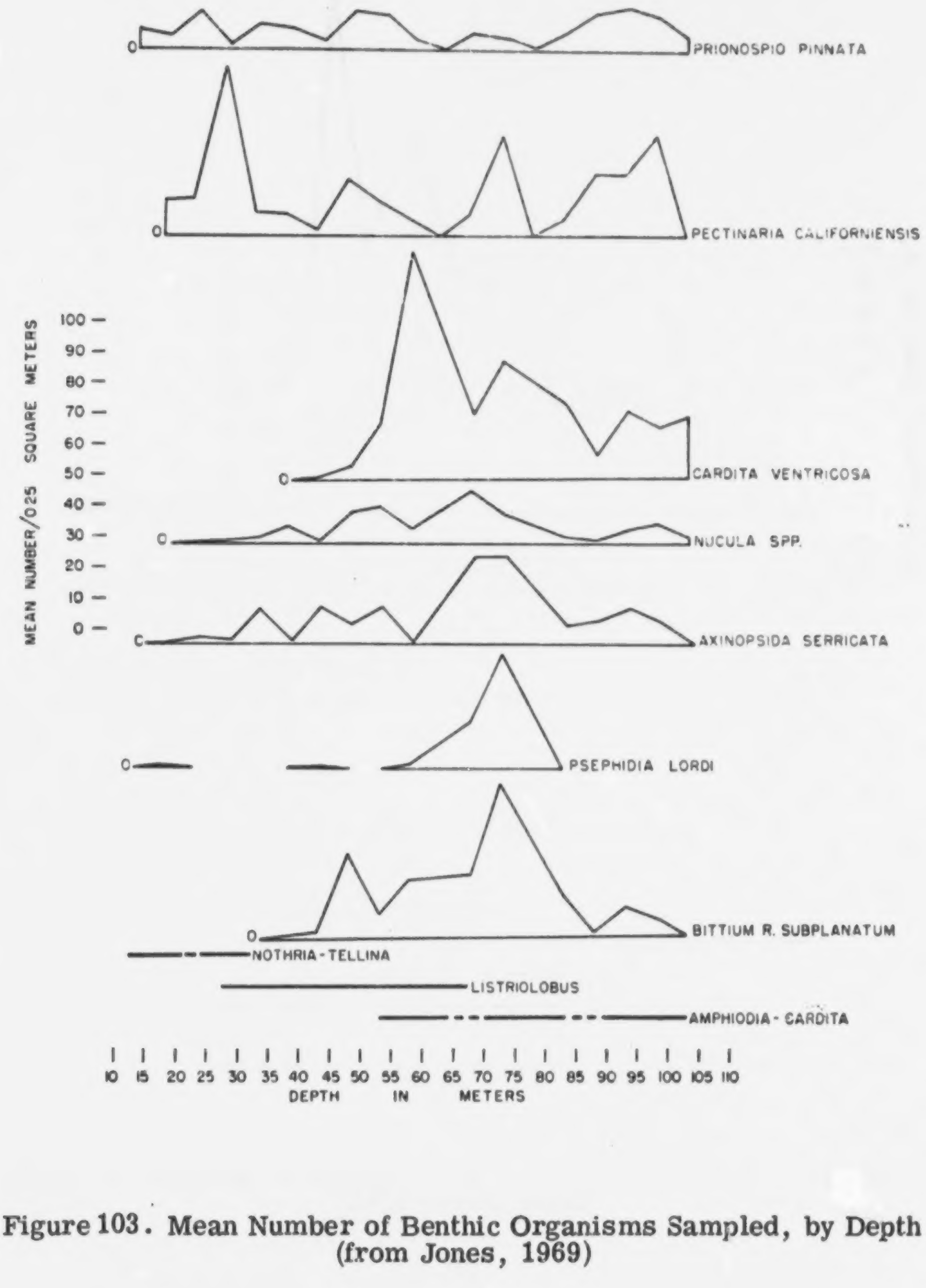


Figure 103. Mean Number of Benthic Organisms Sampled, by Depth (from Jones, 1969)

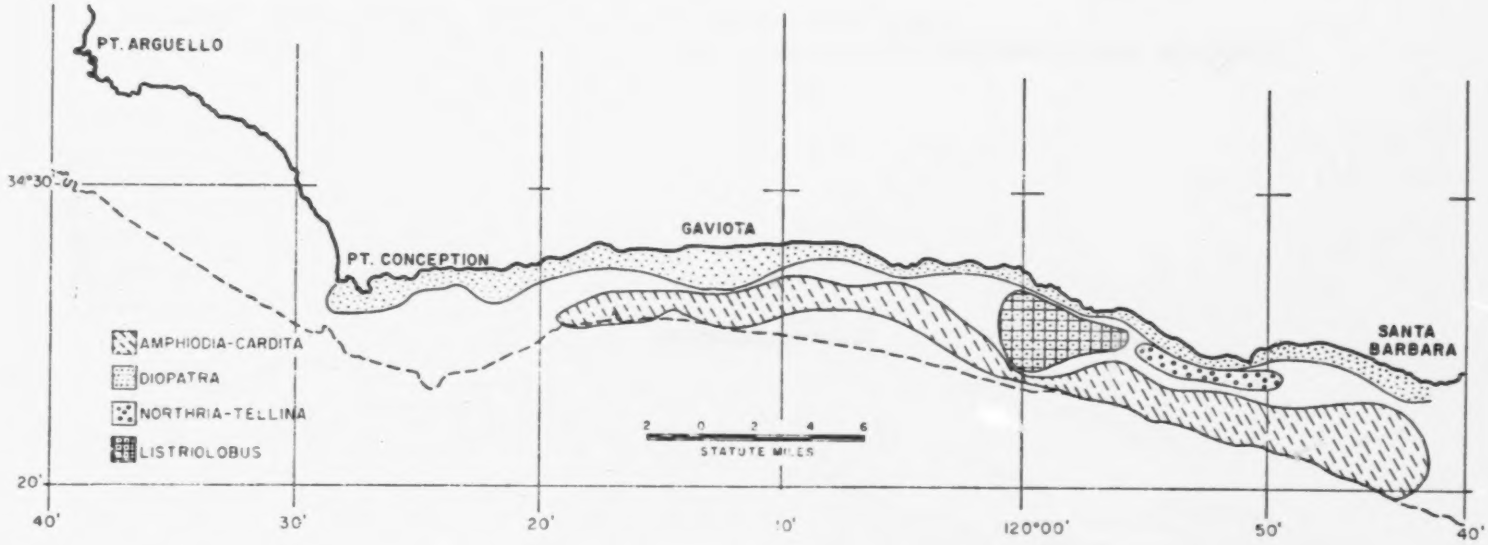

PT. ARGUELLO
PT. CONCEPTION
GAVIOTA
SANTA BARBARA
AMPHIODIA-CARDITA
DIOPATRA
NORTHRIA-TELLINA
LISTRIOLOBUS
2 0 2 4 6
STATUTE MILES
34°30'
20'
40'
30'
20'
10'
120°00'
50'
40'

Figure 104. Distribution of Benthic Macrofaunal Associations on the Mainland Shelf, Point Arguello (Point Conception) to Santa Barbara (from Jones, 1969)

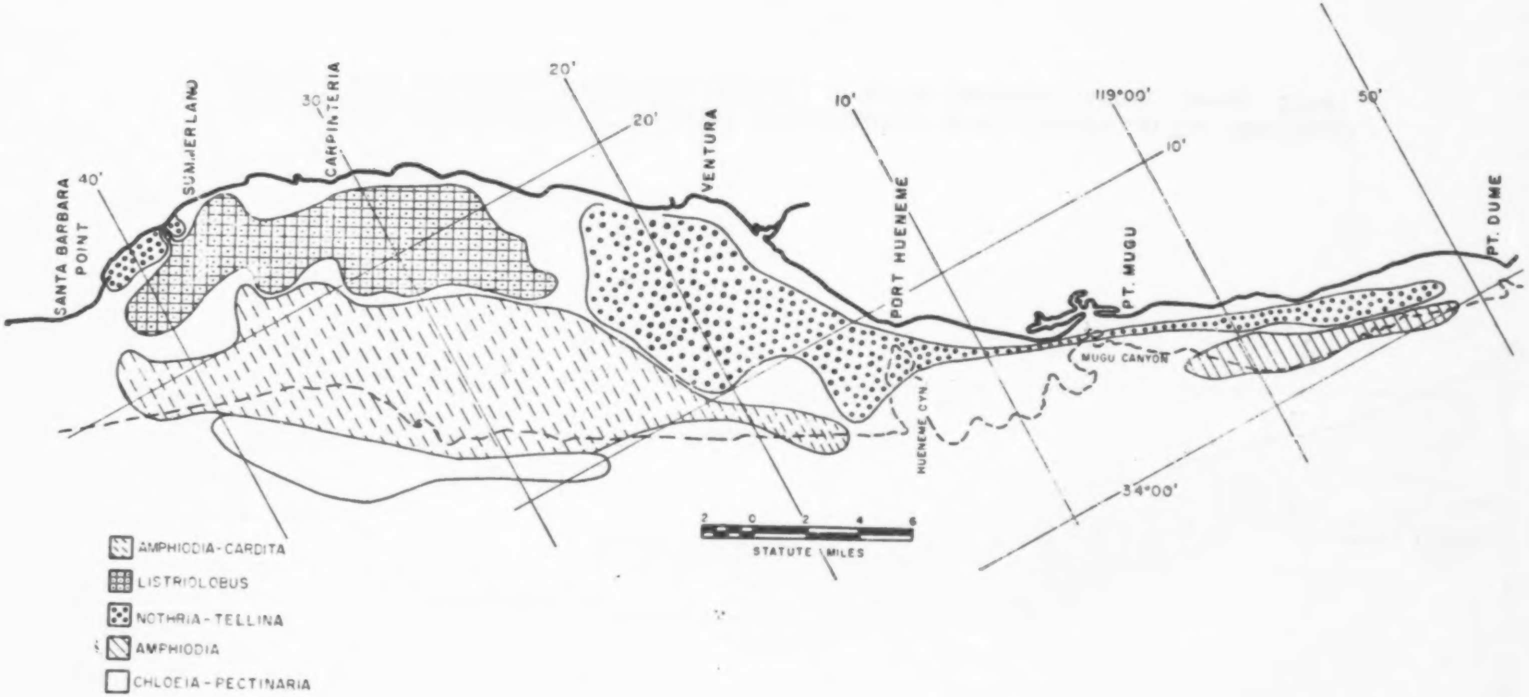

SANTA BARBARA POINT
40'
SUMMERLAND
30'
CARPINTERIA
20'
20'
VENTURA
10'
PORT HUENEME
HUENEME CYN.
119°00'
10'
PT. MUGU
MUGU CANYON
50'
PT. DUME
34°00'
2 0 2 4 6
STATUTE MILES
AMPHIODIA - CARDITA
LISTRIOLOBUS
NOTHRIA - TELLINA
AMPHIODIA
CHLOEIA - PECTINARIA

Figure 105. Distribution of Benthic Macrofaunal Associations on the Mainland Shelf, Santa Barbara to Point Dume (from Jones, 1969)

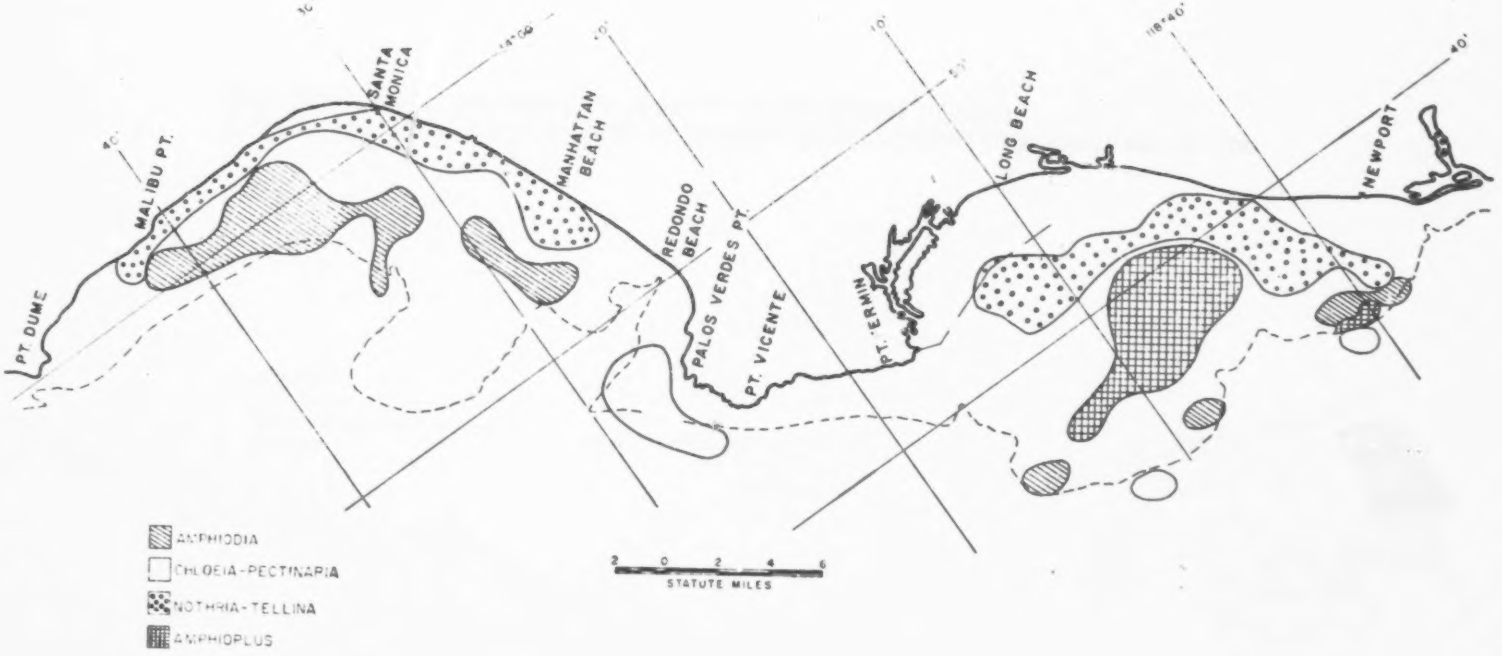

40'
MALIBU PT.
PT. DUME
30'
SANTA MONICA
14°00'
40'
MANHATTAN BEACH
REDONDO BEACH
PALOS VERDES PT.
PT. VICENTE
10'
50'
PT. FERMIN
LONG BEACH
118°40'
NEWPORT
40'
AMPHIODIA
CHLOEIA-PECTINARIA
NOTHRIA-TELLINA
AMPHIOPLUS
2 0 2 4 6
STATUTE MILES

Figure 106. Distribution of Benthic Macrofaunal Associations on the Mainland Shelf, Point Dume to Newport (from Jones, 1969)

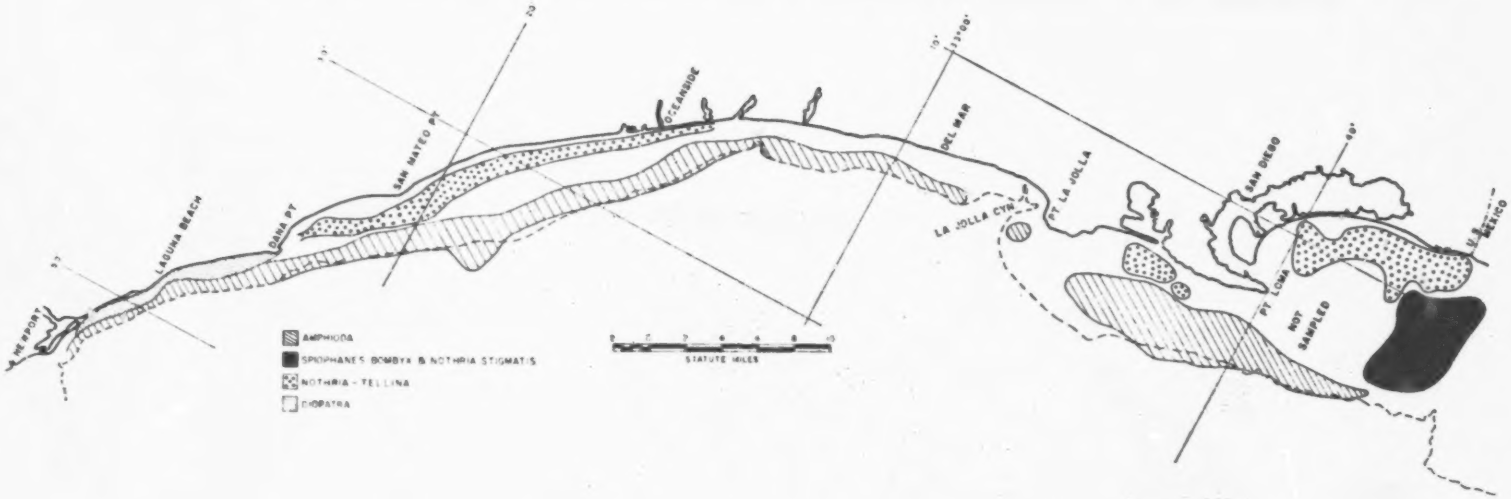

NEWPORT
LAGUNA BEACH
DANA PT
SAN MATEO PT
OCEANSIDE
DEL MAR
LA JOLLA CYN
PT LA JOLLA
SAN DIEGO
PT LOMA
NOT SAMPLED
U.S.
MEXICO
33°00'
10'
40'
AMPHIODA
SPIOPHANES BOMBYX & NOTHRIA STIGMATIS
NOTHRIA - TELLINA
DIOPATRA
0
10
STATUTE MILES

Figure 107. The Distribution of Benthic MacrofaunalAssociations on the Mainland Shelf, Newport to Mexico (from Jones, 1969)

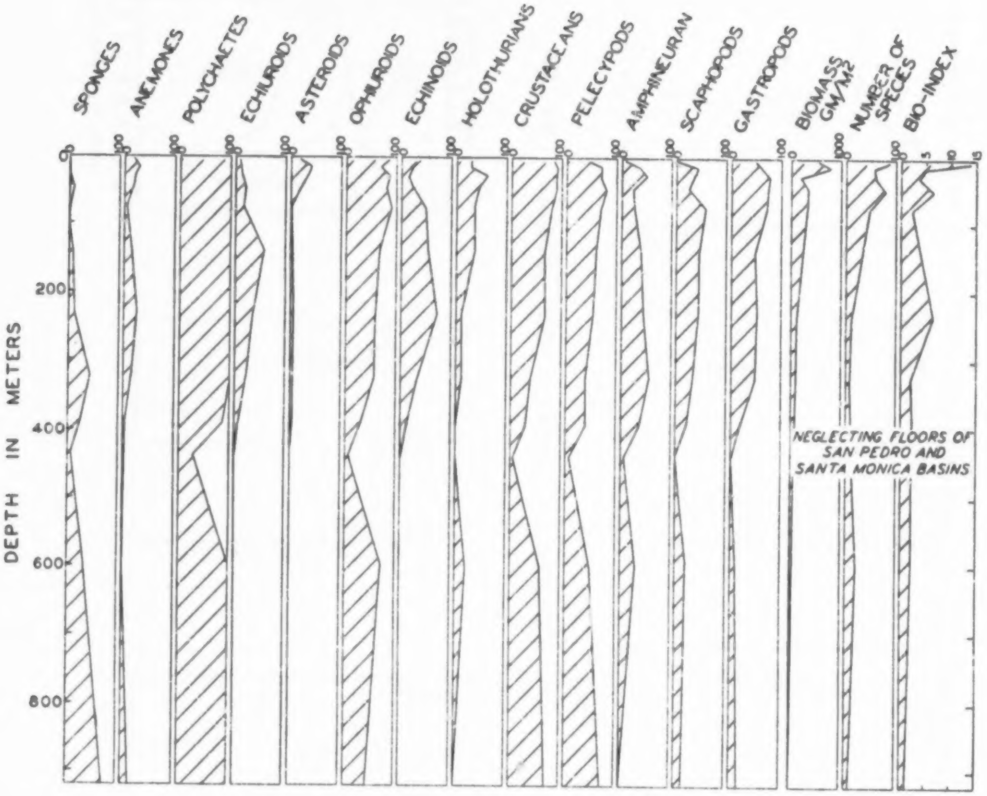


Figure 108. Percentage of 316 Samples, in Various Depth Ranges, That Contain One or More Specimens of Siliceous Sponge, Anemone, and Other Kinds of Animals (from Emery, 1960)

At right is depth distribution of average biomass (exclusive of algal bottoms), average number of species, and average bioindex of samples from all areas except the impoverished bottoms of the San Pedro and Santa Monica Basins.

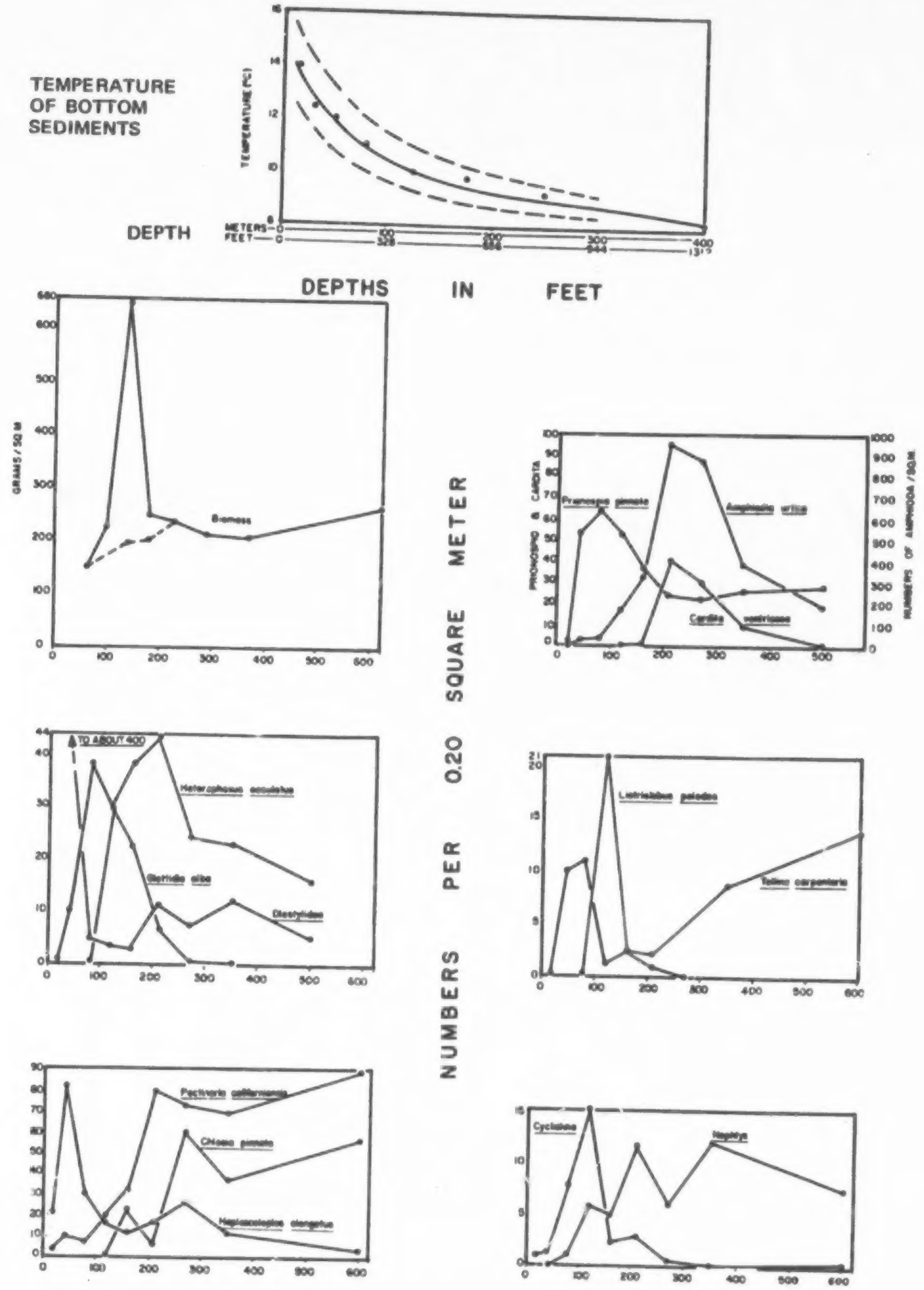


Figure 109. Populations of Representative Species, and Biomass, Related to Depth (from the Allan Hancock Foundation, 1965)

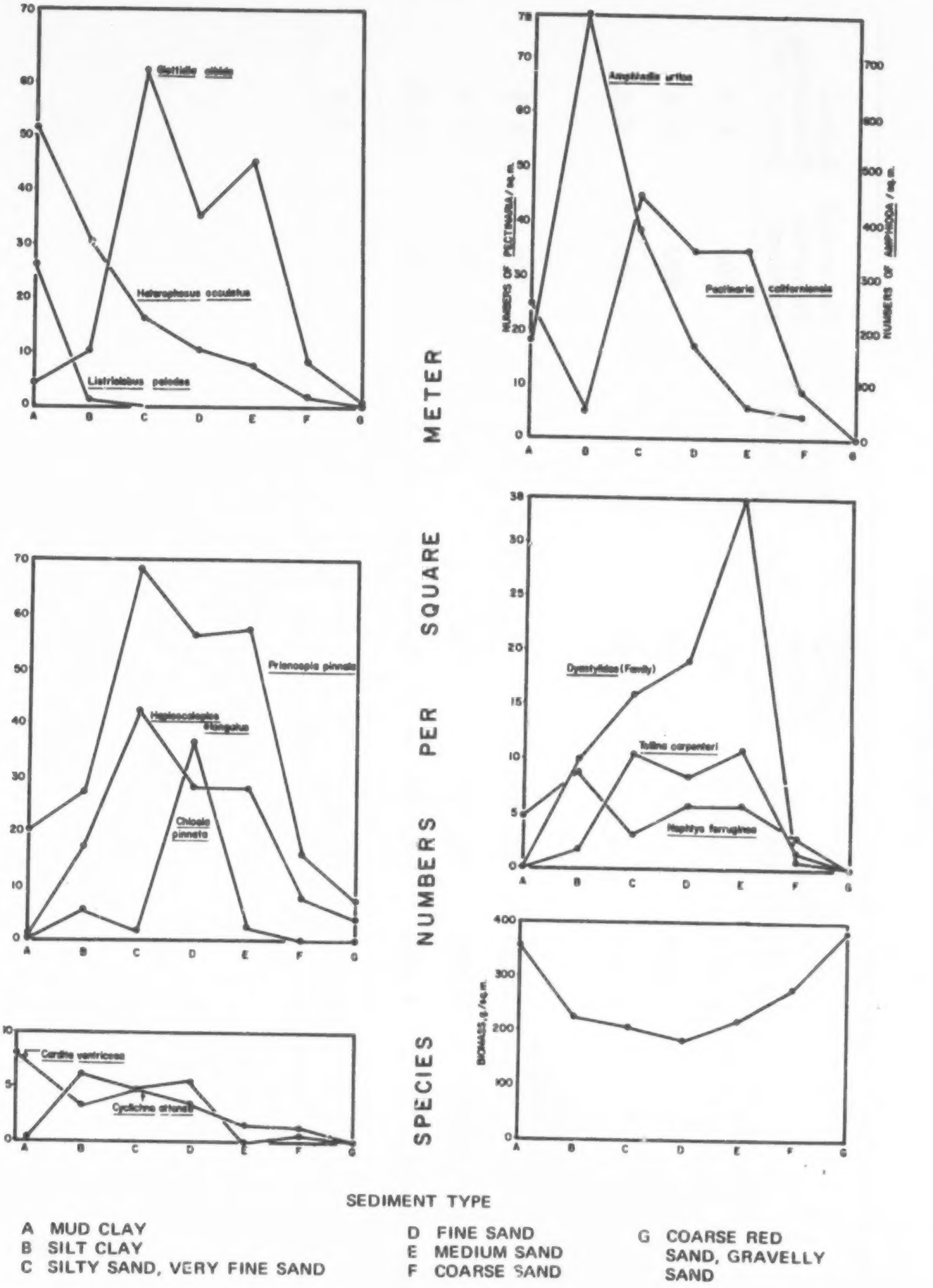


Figure 110. Populations of Representative Species, and Biomass, Related to Sediment Grain Size (from the Allan Hancock Foundation, 1965)

Table 96. Biomass of Benthonic Animals (Wet Weights)
(from Emery, 1960)

	Area (sq miles)	Area (sq km)	Estimated Average Biomass (gm/sq meter)	Standing Crop (tons x 10^6)	Estimated Turnover (percent)	Annual Production (tons x 10^6)
Mainland shelf	1,890	4,900	300	1.5	200	3.0
Island shelves	1,390	3,600	50	0.2	200	0.4
Bank tops	2,420	6,260	50	0.3	200	0.6
Basin and trough slopes, and other deep irregular areas	15,350	39,700	80	3.2	100	3.2
Basin and trough floors	8,980	23,200	8	0.2	50	0.1
Continental slope	1,960	5,070	20	0.1	50	0.05
Total	31,990	82,730		5.5		7.3

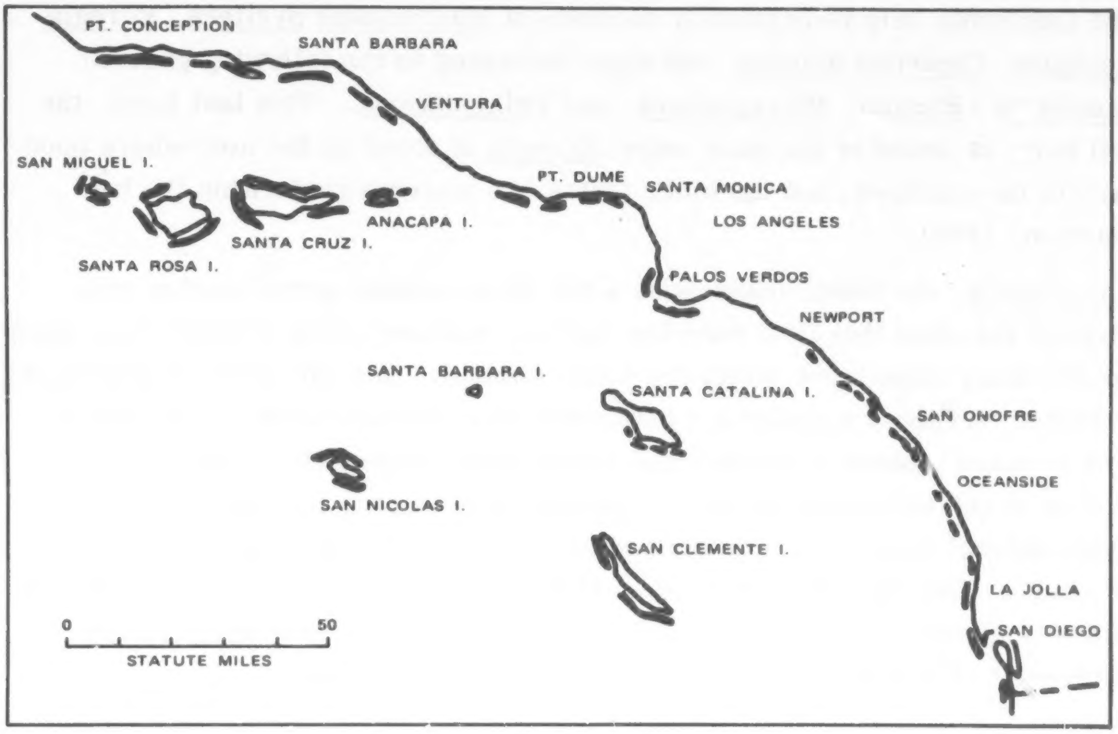

PT. CONCEPTION
SANTA BARBARA
VENTURA
SAN MIGUEL I.
PT. DUME
SANTA MONICA
ANACAPA I.
LOS ANGELES
SANTA CRUZ I.
SANTA ROSA I.
PALOS VERDOS
NEWPORT
SANTA BARBARA I.
SANTA CATALINA I.
SAN ONOFRE
OCEANSIDE
SAN NICOLAS I.
SAN CLEMENTE I.
LA JOLLA
SAN DIEGO
0
50
STATUTE MILES

Figure 111. Southern California Region Showing Area of Kelp Beds Designated by the Department of Fish and Game (from North and Schaeffer, 1964)

resources within its boundaries. Commercial fish such as sea bass, sculpin, lobster, and abalone are harvested within this habitat. Sport fishing, a very popular activity, is also practiced within these boundaries. Animals forms observed grazing in kelp beds include:

a.	sea urchin	*Strongylocentrotus purpuratus* *S. franciscanus* *Lytechinus anamesus*
b.	isopod	*Idothea resecata*
c.	abalone	*Haliotis rufescens* *H. fulgens*
d.	snail	*Astrea undosa* *Norrisia norrisii*
e.	opaleye	*Girella nigricans*

The California kelp bed typically consists of *Macrocystis pyrifera*, *Egregia laevigata*, *Gigartina armata*, and algae belonging to the following genera: *Laminaria*, *Eisenia*, *Pterygophora*, and *Pelagophycus*. This last form, the bull kelp, is found at the outer edge; *Egregia* is found on the near-shore boundary in the shallows; and the other forms are intermingled within the bed (Dawson, 1966).

Macrocystis, the most conspicuous algal form, attains great heights with parts of the plant that float near the surface forming a kind of sheltering canopy for the many organisms within the water column. The life cycle of *Macrocystis* is rather complex, displaying a heteromorphic and alteration of generation type of history which is widespread among brown seaweeds. About 12-14 months is the estimated period for *Macrocystis* to complete its life cycle under natural conditions. In laboratory culture, the gametophytic stage is reached in less than one month (Neusal and Haxo, 1968). Large temperature fluctuations are known to occur in kelp beds, and apparently temperature changes of 11°F are not considered extreme (Quast, 1968).

Fouling

Fouling is produced by organisms that attach, grow, and accumulate on almost any substrate -- natural or man made -- that is in contact with the marine environment. The communities found on vertical surfaces or rocky surfaces are, in most cases, descriptive of the potential fouling community to depths of about 150 ft. A list of the plants and animals common in the rocky intertidal area of the San Diego region is given in table 97. Algae are the most conspicuous fouling forms of the intertidal area. A list of the more common intertidal algae forms of the California shelf and their relative abundance is presented in table 98. *Corallina* (a green alga), *Egregia* (the feather boa kelp), *Gigartina* (a red alga), and *Phyllospadix* (the surf grass), are the most common intertidal plants listed.

The dominant intertidal organisms found in two transects of Diablo Cove, California, are shown by figures 112 and 113 (North, 1969). The common organisms found at -1.0 ft to +6.5 (mean low water) are given. Encrusting or small bushy types plants (*Ralphsia*, *Corallina*, *Lithothamnion*, *Endocladia*) predominate; littorines, barnacles, and limpets are the predominant animals

Table 97. Rocky Intertidal Plants and Animals -- San Elijo Lagoon, San Diego County (from Turner et al, 1965)

- Algae
  - *Ulva* sp.
  - *Gelidium purpurascens*
  - *Corallina officinalis*
  - *C. vancouverensis*
  - *Zonaria farlowii*
  - *Bossiella orbigniana*
- Invertebrata
  - Annelida
    - Serpulidae
    - Cirratulidae
  - Cnidaria
    - *Anthoploeura elegantissima*
  - Arthropoda
    - *Cirolana harfordi*
  - Mollusca
    - *Olivella biplicata*
    - *Mytilus californianus*
    - *Chama pellacida*
    - *Nuttallina californica*
    - *Epitonium* sp
    - *Turbonium kelseyi*
    - *Acmaea pelta*
  - Bryozoa
    - *Membranipora tuberculata*

Table 98. Intertidal Algae: Most Common Marine Plants and Relative Abundance (from the Allan Hancock Foundation, 1965)

Corallina vancouveriensis	617
Egregia laevegata	559
Gigartina canaliculata	534
Phyllospadix sp	514
Gigartina leptrohynchos	426
Gastroclonium coulteri	314
Bossiella gardneri-dichotoma conplex	277
Pterosiphonia dendroidea	258
Gelidium coulteri	238
Rhodoglossum affine	234
Gigartina spinosa-armata conplex	220
Chondria nidifica	213
Plocamium pacificum	201
Gilidium cartilaginium v. robustum	195
Porphyra fastigiata	179
Pterocladia pyramidale	172
Ulva californica	167
Corallina officinalis v. chelensis	162
Chaetomorpha areae	160
Centroceras clavulatum	156
Prionitis lanceolata	155
Porphyra perforata	145
Lithothrix aspergilbum	142
Melobesia mediocris	134
Enteromorpha compressa	129
Gracilariopsis sjoestedtii	128
Gelidium purpurasceno	125
Laurencia pacifica	116
Pachydictyon coriaceum	115
Gymnogongrus leptophyllus	112
Ceramium eatonianum	109
Chondria decipiens	109

Table 98 (Cont'd)

Gracilariopsis andersonii	**108**
Gigartina volans	**105**
Gelidium crinale v. luxurians	**102**
Nienburgia andersoniana	**99**
Gracillaria cunninghamii	**98**
Eisenia arborea	**94**
Cryptopleura violacea	**94**
Spermothamnion synderae	**85**
Polysiphonia collinsii	**85**
Pterosiphonia baileyi	**83**
Heldenbrandia protoypus	**76**
Jania natalensis	**70**
Rhodymenia palmettiformis	**62**

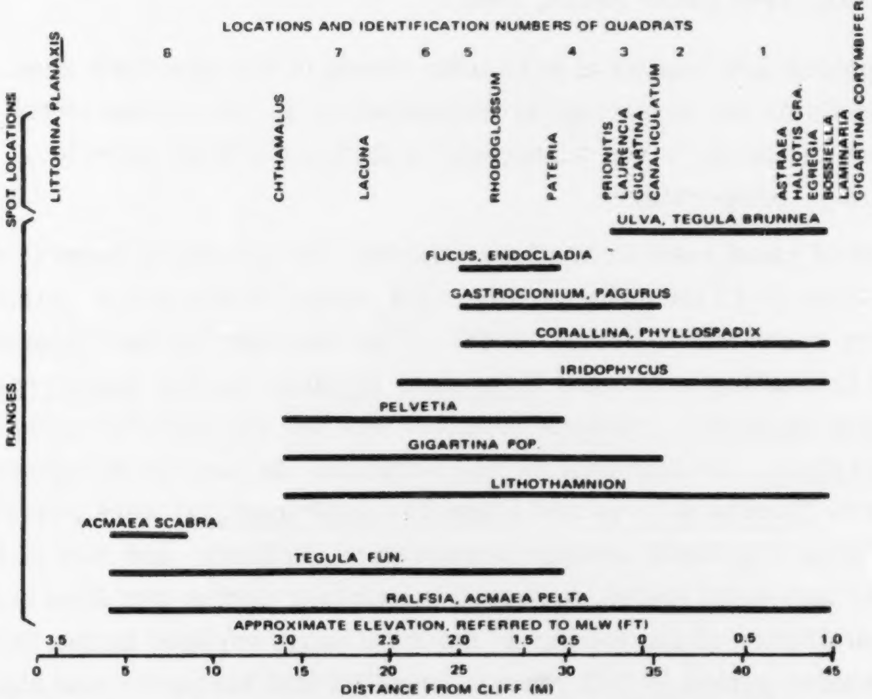


Figure 112. Ranges and Locations of Dominant Organisms, Transect A, South Side of Diablo Cove, November 12, 1966 (from North, 1969)

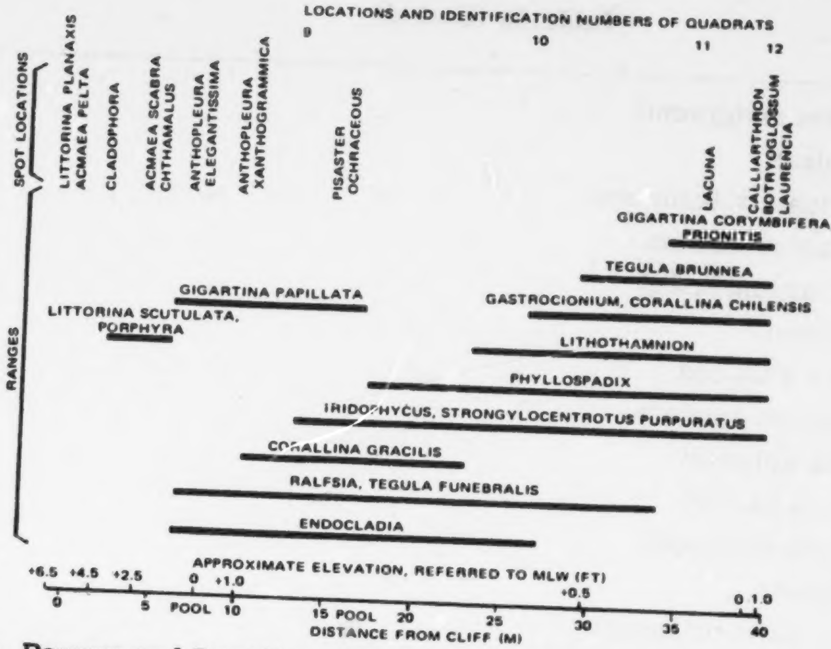


Figure 113. Ranges and Locations of Dominant Organisms, Transect B, Central Diablo Cove (the Approximate Likely Future Location of Discharge) November 12, 1966 (from North, 1969)

found. Species are located at particular levels of the intertidal zone. Their niche depends on the physiological tolerances of the organisms to the many parameters of exposure and submergence during the tidal cycle (e.g., respiration, salinity, temperature).

In a series of panel tests in Monterey Harbor, in both short-term (1 month) and long-term (3-12 month) exposure tests, about 75 species of animals and plants were recorded (Haderlie, 1968). The dominant fouling organisms were erect and encrusting bryozoans (Hippothoa hyalina, Lyrula hippocrepis, Crisulipora occidentalas). Balanus crenatus was the dominant barnacle and Spirorbis spirillum, the dominant fouling serpulid. In long-term exposure tests, wood borers (Bankia setacea and Limnoria quadripuntata) were prevalent. No correlation was found among temperature, salinity, and rate of fouling, except that increased fouling occurred in summer during late June and early July. Examination of the fouling on mooring buoys exposed in San Diego Bay for an extended period (4-1/2 years) revealed that barnacles and algae were the dominant forms in the splash zone, while tunicates and barnacles were the most conspicuous on the submerged surfaces, with mussels, bryozoans, hydroids, and tube worms also present but to a lesser extent (Drisko, 1967).

In deep ocean fouling tests off San Miguel Island, Muraoka (1965, 1966) reported that hydroids, sea anemones, amphipods, and borers were the common fouling organisms. Buoys at about 240 and 940 ft below the surface were fouled heavily with a pink colored sea anemone. Typical fouling organisms, such as barnacles and encrusting bryozoa, are not dominant forms of the deep water fouling community, although fouling is judged to be continuous up to a depth of 462 ft (Hutchins, 1952). At the depths we are considering, fouling by sea anemones, hydroids, and perhaps tubeworms can be assumed. Algae should be absent.

In studies concerned with heat transfer and material selection for deep ocean applications, surfaces of cupronickel, naval brass, silicon bronze, beryllium copper, HC copper, HH brass, and titanium were materials that inhibited fouling growth (C. F. Braun and Co., 1965). This report also indicated that metal surfaces maintained at 100°F were free of fouling growths.

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Appendix A

NOTES ON ESTIMATING COASTAL CURRENTS

Coastal currents at many places on the continental shelf have not been measured. Data may be available on certain components of the current profile, but might have to be estimated for others. This appendix explains the method for such estimates in this report. The following vector equation expresses the composition of coastal currents:

$$V(z) = V_t(z) + V_c(z) + V_w(z) + E(z)$$

where $V(z)$ is the vertical current profile at any time,
$V_t(z)$ is the tidal current,
$V_c(z)$ is the coastal drift,
$V_w(z)$ is the wind drift, and
$E(z)$ is a residual current component assumed to approximate zero for the present purpose.

These components and synthetic values for them, which may be used in lieu of actual measurement, are discussed below.

Tidal Currents: $V_t(z)$

At a location on the open shelf away from the effects of the shoreline, one can expect to find rotary tidal currents. The current vectors will generally describe an ellipse with the major axis in the direction of maximal ebb and flood current. The ellipticity of the ellipse (ratio of the minor to major axes), or the ratio of minimal to maximal tidal current velocities (r) may be estimated to be 0.5, although in theory the ellipticity depends on latitude, being the ratio of the inertial to tidal angular frequency, or:

$$r = \frac{2\omega \sin\phi}{\frac{2\pi}{T}} = 1.033 \sin\phi \qquad \text{(Defant, p 494)}$$

where ω = angular velocity of earth's rotation
ϕ = latitude
T = tidal period

Where influenced by shore or seabed, tidal flow will tend to align with that boundary. Consequently, near-shore locations will exhibit rectilinear flow, or reversing currents, while near-bottom flow along slopes or in ravines will tend to be parallel with the isobaths or along the ravine axis respectively. Approaching the coast, the tidal ellipse will decay into a reversing flow alongshore, so that the ellipticity will approach 0.

We assume that the vertical structure of the tidal current will be affected only by bottom friction. This assumption is based on the driving force being constant throughout the water column. Over a relatively smooth bottom, the bottom effect may become noticeable at 20 to 30 feet above the bottom, with current speed decreasing exponentially to 60 percent of its near-surface value at 15 feet above the bottom. These relationships are based on the work of Hellend Hansen and Fjelstad (Sverdrup, p 578-9).

If available data shows only maximal ebb and flood speeds, with directions, and we can assume a rotary tidal current, then the current's ellipticity can be synthesized by assuming the minor axes to be 50 percent of the major and 90 degrees to the right. Each hour during a semidiurnal tidal period, the direction of flow will turn clockwise $29^{\circ}\left(\frac{360^{\circ}}{12.4 \text{ hr}}\right)$.

The further assumptions may be made that during springs and neaps (full and new moon) the speeds will be increased by 20 percent, and during quadrature they will be reduced by 20 percent (Marnier, 1926).

Expected tidal current speeds in open coastal areas will range from 0.10 to 1.0 knots, with most likely speeds in the mid-range (0.4-0.6 knots) (Emery, Bumpus).

Coastal Drift: $V_c(z)$

Generally, the coastal drift will range from 0.1 to 0.5 knots (2.4 to 12 nm per day) with the flow parallel to the coast. However, in regions near major current systems, such as the Gulf Stream and California Current, eddies or vortices may be produced by the lateral shear between the offshore current and inshore waters. These vortices will become entrained in the coastal current pattern. This phenomenon is especially apparent from Cape Hatteras to the tip of Florida. The nearshore circulation undergoes a seasonal reversal off California. For part of the year, the southbound California Current predominates; at other times, the northbound Davison Current develops inshore of the California Current.

The vertical velocity gradient of the coastal drift in 250-ft depths is assumed to decrease linearly to 50% of the surface layer speed down to the bottom friction layer (20 to 30 ft off the bottom), and then decay in a manner similar to the tidal current (30% of surface velocity at 15 ft off bottom). This assumption is based on the coastal drift being the result of gradient flow, and that the slope of the isobars relative to geopotential surfaces, decreases as one proceeds from the surface to the bottom.

Near the mouth of estuaries a bottom drift into the estuary can be expected. This is a replacement flow that compensates for the entrainment and mixing of deep salty water with the outflowing river water. In general, the greater the outflow the greater the replacement or bottom flow.

Wind Drift: $V_w(z)$

Surface currents caused by local winds and transport from waves are assumed to be 2.0 to 3.0% of the wind speed and in approximately the same direction as the wind (Weigel R., p 319-320)(see figure 114). Theoretical work (Ekman) shows surface drift to be 45 degrees to the right of the wind in the northern hemisphere, for a boundless ocean, and to exhibit a somewhat smaller angular displacement in shallow water. Some shallow water measurements have shown surface drift to be about 20 degrees to the right of the wind, but these measurements are highly variable (Doebler).

The vertical profile of currents caused by wind stress is a function of eddy viscosity, density stratification, and depth. Ekman's theoretical work

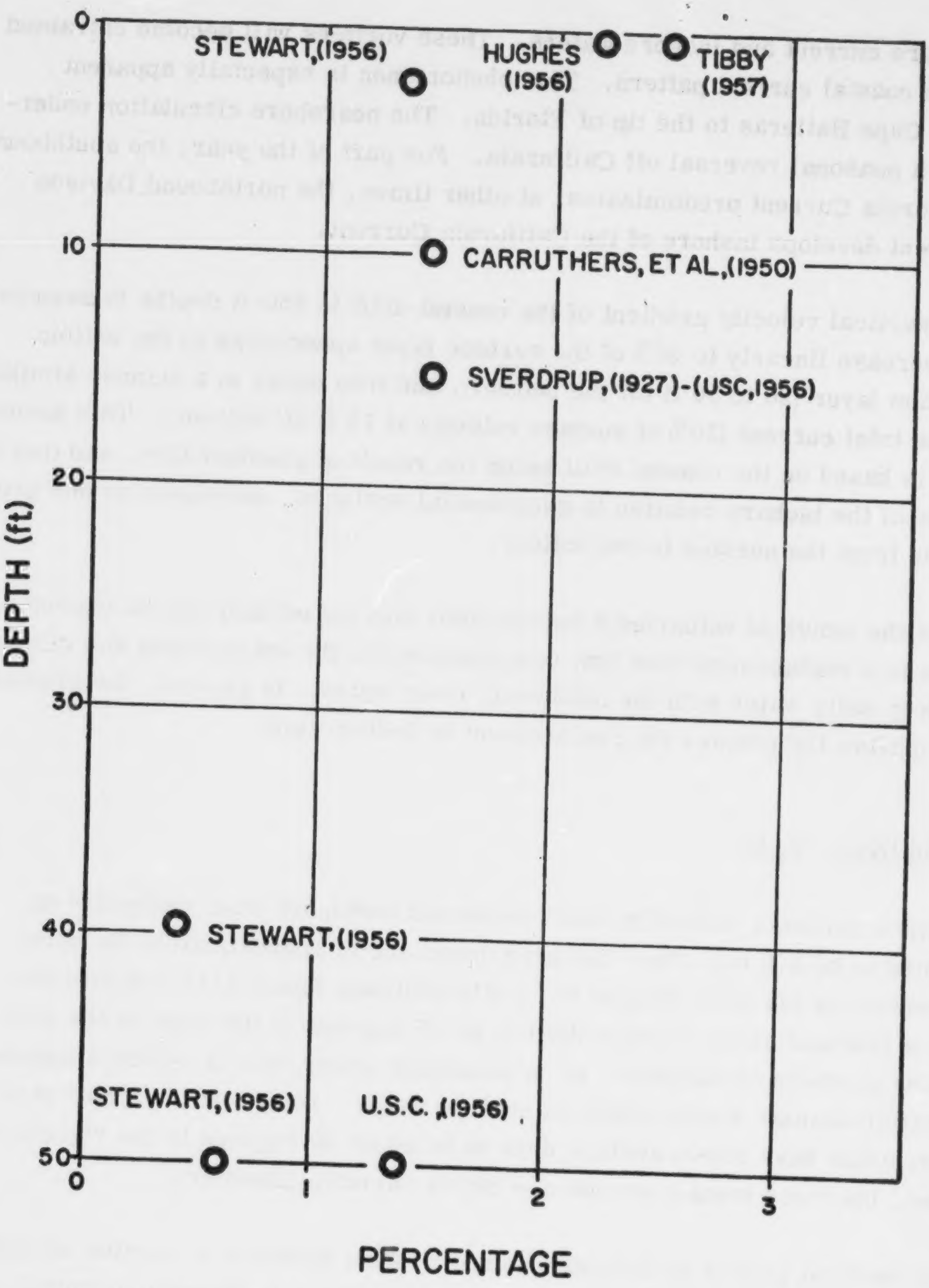

Figure 114. Current Velocity as Percentage of Wind Velocity (from State of California, 1965)

defined the layer of frictional influence, D, as

$$D = \pi \sqrt{\frac{A}{\rho \ \omega \ \sin \phi}}$$ **(Neuman & Pierson, p 217-220)**

where A = eddy viscosity coefficient (cm^{-1} sec^{-1})
ω = angular velocity of earth rotation (7. 29 X 10^{5} sec^{-1})
ϕ = latitude
ρ = density (1.02±)

If one assumes eddy viscosity to be a constant between 200 and 500 (Neuman & Pierson, p 210-11), the density to approximate unity, and latitudes between 30 and 40 degrees, then D is between 65 and 100 meters, roughly the site depth.

The vertical profile of current speed decays exponentially as $e^{-\pi z/D}$ so that when z = D, V = 4% of the surface; when z = D/3, V = 35% of the surface; and z = D/2, V = 20% of the surface velocity. This model applies to homogeneous ocean.

When a thermocline develops, and a two-layer model is assumed with a linear density gradient in the surface layer, and homogeneous lower layer (Neuman and Pierson p 219, figure 8), the vertical profile decays rapidly in the top layer, reaching about 50% of the surface value at the thermocline, in the case where thermocline depth is 20% of the total depth.

However, for an initial estimate, the wind-driven current profile for a site whose depth approximates D, can be arrived at by using 2% of the wind speed for the surface layer speed, then applying a damping factor

$$e^{-\pi z/D} \quad \text{or} \quad e^{-z/80}$$

where z is in feet below the sea surface.

Summary

The following synthetic components may be used when data are insufficient.

Tidal Current (V_t)

1. Greatest velocity in surface layer: 0.4 knots.
2. Vertical velocity gradient: constant down to 30 feet off the bottom, then an exponential decrease to 50% of surface velocity (0.2 knots) at 15 feet off the bottom.
3. Horizontal pattern: ellipse with minor axis 50% of major.

Coastal Drift (V_c)

1. Velocity in surface layer: 0.3 knots.
2. Vertical velocity gradient: linear decrease to 50% of surface speed (0.15 knots) 30 feet off the bottom, then an exponential decrease to 25% (0.08 knots) at 15 feet off the bottom.
3. Horizontal pattern: parallel to isobaths.

Wind Drift (V_w)

1. Velocity in surface layer: 2% of wind velocity.
2. Vertical velocity gradient:
   Weak thermocline: damped exponentially by $e^{-z/80}$ where z is in feet, so at 100 feet $V_w = 28\%$ of surface and at 200 feet $V_w = 8\%$ of surface velocity. Strong shallow thermocline, damped exponentially by $e^{.7z/d}$ where d = depth of thermocline. As a result, 50% of the velocity will be damped bythe thermocline ($z = d$), and from there to the bottom damping will be similar to the weak thermocline case, namely, $e^{-z/80}$ damping (but use $z = 0$ at the thermocline where velocity is 50% of sea surface velocity)

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